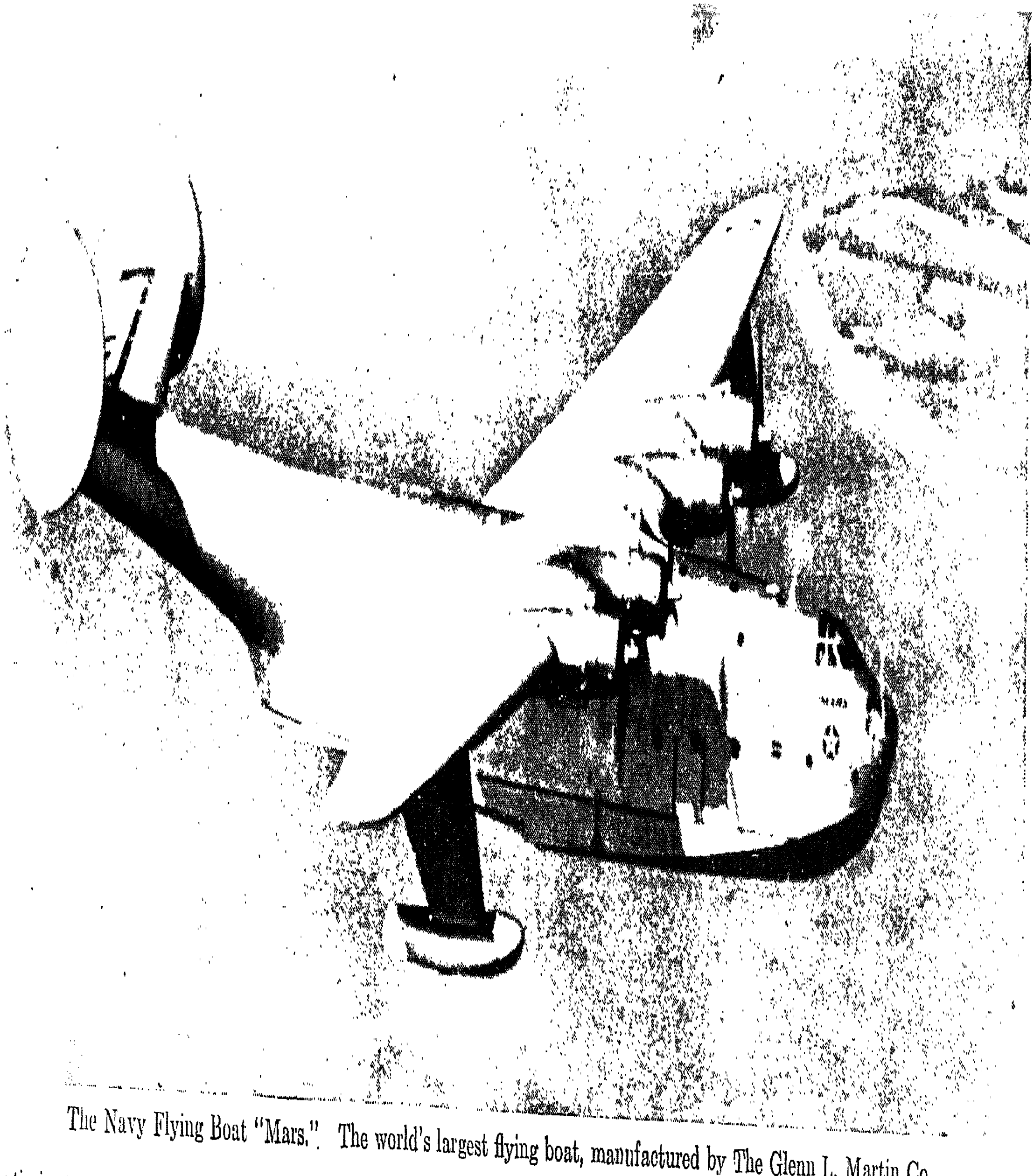

The Navy Flying Boat "Mars." The world's largest flying boat, manufactured by The Glenn L. Martin Co.

(*Frontispiece.*)

FUNDAMENTALS
FOR THE
AIRCRAFT MECHANIC

BY

JAMES M. MARKLEY

Supervisor of Mechanics' Training, Eastern Air Lines, Inc.

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK AND LONDON

1943

FUNDAMENTALS FOR THE AIRCRAFT MECHANIC

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

Owing to the present emergency, it has become necessary for the aeronautical industry to train many people previously employed in other fields. Because many of these people have never hitherto performed mechanical work, it is necessary to give them a basic course before they can be given specialized training.

During this basic course, they are taught how to use their hands, the use and care of tools, and the fundamentals of airplane construction, maintenance, and operation. This course can also be used as a screening process to eliminate those not mechanically inclined and to determine the specialized field for which the remaining students are qualified.

To the author's knowledge, there are no books available that are applicable to basic training. Most books have been written either for aircraft or for aircraft engine maintenance and cover only a specialized field. Such books give little attention to the fundamentals of sketching, blueprint reading, or shop mathematics, which are essential to the student if he is to have an intelligent understanding of his specialized training.

This book has been written as a textbook for a basic course and is not intended to be conclusive enough to produce a specialist in any of the branches covered. It includes a sufficient amount of sketching, blueprint reading, and shop mathematics for the student to understand the material to follow. The remaining material gives the student a basic understanding of most of the systems and materials used in the airplane, as well as the simple theory by which these systems work.

A laboratory course should be given in connection with this text to instruct the student in the use and care of hand tools. Experiments should also be performed in the subjects being taught. This is an important item and should not be overlooked. The author has not drawn up such a laboratory course to accompany the present work because shop practices, equipment, etc., vary with different organizations.

This volume can be used as a textbook for pilots, flight engineers, and mechanics and as a reference book.

The author wishes to express his deep appreciation to the following persons and organizations for their kind assistance in the preparation of the material: R. B. Abrames, Electrical Department, Eastern Air Lines, Inc.; I. L. Cole, Hydraulic Department, Eastern Air Lines, Inc.; Maintenance Department, Eastern Air Lines, Inc.; Aeronca Aircraft Corporation; Aluminum Company of America; Propeller and Airplane Division, Curtiss-Wright Corporation; Bendix Stromberg Division, Bendix Aviation Corporation; Donald Sprague, Douglas Aircraft Company, Inc.; Dzus Fastener Company, Inc.; Electric Storage Battery Company; Hamilton Standard Propellers, Division of United Aircraft Corporation; Lockheed Aircraft Corporation; Lord Manufacturing Company; Lycoming Division, Aviation Corporation; Macwhyte Company; The Glenn L. Martin Company; Parker Appliance Company; Pratt & Whitney Aircraft; Scintilla Magneto Division, Bendix Aviation Corporation; Wright Aeronautical Corporation.

JAMES M. MARKLEY.

MIAMI, FLORIDA,
September, 1943.

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FUNDAMENTALS FOR THE AIRCRAFT MECHANIC

INTRODUCTION

Purpose

In the present emergency, it is mandatory that an aircraft mechanics training program be inaugurated to train aircraft and aircraft engine mechanics for the maintenance of civil and military aircraft. These aircraft, as a whole, will be engaged in the transportation of vital war materials and personnel. Since the number of mechanics required by such a program is very large, it is necessary to develop untrained personnel into student mechanics and maintenance personnel. This book covers basic training only. Additional training in some specialized work will be necessary later.

This text is designed to give each man only a basic knowledge of aircraft. The student's response to the basic training will assist the instructing personnel in determining the channels into which he should be guided for further specialized training. This specialized training will fit the student for one of the many jobs required in the maintenance and overhaul of aircraft and its components, each of which, regardless of the viewpoint assumed by the mechanic, is of equal importance with every other job from the standpoint of safety and the welfare of personnel. As the student advances through the various stages of the upgrading program, he will be expected to impart the knowledge he has gained to others less well informed than himself. Eventually, those who have proved their ability will be able to assume important roles in the aviation industry after the present emergency has passed.

The high standards set up by the aircraft industry require men of high moral character, integrity, and sound judgment. Therefore, this type of training is not meant for anyone who is

inclined to be negligent, careless, or inattentive. Aircraft maintenance personnel are required to be resourceful, but they are also required to do precise work at all times. They must be careful that enthusiasm or overconfidence does not cause them to fall into errors that might cause serious damage or possibly loss of life. When in doubt, it is better to ask than to take a chance and make a mistake that may cause a serious accident or damage to equipment.

In the present emergency, the air lines are expanding to a point that would normally take years to reach. Personnel entering upon these projects at the present time will have a better opportunity to fit themselves for the future operation of this vast industry, which is now being rapidly developed to reach all countries and even relatively small communities by means of feeder lines. Anyone with any imagination can see that the future for qualified personnel is unlimited. The individual's place in the future permanent setup will depend entirely upon his ability to fit into the ultimate picture.

The air lines constitute one industry that depends entirely upon results. All maintenance operations on aircraft (including repair and overhaul) must be fully recorded and signed for by the man performing the work; in the event of an accident due to carelessness, the mechanic who performed the operation can be traced through these records. Conversely, the student who is careful and resourceful will make a permanent place for himself in this vast industry.

Aircraft Maintenance and Practices

Maintenance of equipment today is based on previous experience gained by the operator over a number of years and varies greatly from methods used in the past. This term covers not only periodic inspection, overhaul, or repairs to prevent failure of the aircraft or its components but also the application of new methods or material to give greater life and alteration in equipment to prevent wear or failure in the future.

In the early days of aviation the airplane was maintained by the pilot, who may also have been the designer and manufacturer. The First World War developed a need for mechanics exclusively for the maintenance of the airplane. These mechanics as a whole were not pilots, although many became pilots after the war.

With the growth of aviation the airplane grew from the flimsy, inefficient postwar biplane, constructed mainly of wood or steel and fabric, to the present-day luxury liner of all-metal construction. Increased air traffic called for more efficient planes, lower rates, and increased flying hours. This was accomplished by the manufacture of fleets of planes with complete interchangeability of parts and the development of a highly specialized crew of mechanics. The interchangeability of parts made it possible to remove components for periodic inspection without extensive loss in flying hours. The outgrowth of such a system is the present-day air line with its various branches.

The high standards required for public and private welfare have rigidly controlled the methods of manufacture, inspection, maintenance, overhaul, and repair of all aircraft. Because the slightest laxity in the correct performance of duties may result in loss of life and property, the aeronautical industry is one of the few that must be licensed by the Federal government.

The branch of the government responsible for this is the Civil Aeronautics Administration (CAA). Its duties cover the issuance of all licenses required in the aeronautical industry and of all laws and regulations concerning the safe manufacture, registration, operation, and maintenance of aircraft operating over the continental United States and its possessions. The mechanic is required to pass rigid theoretical and practical examinations before he can receive a certificate of competency in respect to aircraft or aircraft engines. The maintenance methods of the air lines, such as periodic inspections or overhauls, are covered by competency letters issued by the CAA. These cannot be altered or transferred without permission of the administration. A change for the better in the competency letter allotted is brought about only by improved methods and equipment.

Periodic inspections are usually standard company procedure and are covered by inspection sheets. A typical air-line 100-hr. inspection sheet is shown on pages 4 to 7.

Safety Regulations

Since safe operation is of primary importance, all air lines make it mandatory that all mechanical work be done under the

BASE

E.A.L. Inspection—Douglas DC-3 and DST Airplanes

Date____________________Station____________________Ship No.____________

All items on this form applicable to equipment installed and on type airplanes designated plus items inserted by inspector on this form and supplementary forms, which become a part of this form, are to be executed. "C" items are to be performed by Mechanic and "I" items by Inspector. A check mark in the "NOTE" column indicates special work on that particular item, which will be explained fully in blank spaces at end of group or on back of sheet.

Item No.	Operation	DC-3 DST	I C	Mechanic Left	Mechanic Right	Note	Inspector Left	Inspector Right
	ENGINES							
1	Remove rear cowl	3T	C					
2	Remove anti-drag ring cowl	3T	C					
3	Wash engine and mount	3T	C					
4	Cylinder heads (visual—skeet any suspected area with oil on compression	3T	C					
5	Compression by turning engine and listening	3T	C					
6	Remove oil strainer and clean	3T	C					
8	Drain fuel sumps and strainers	3T	C					
9	Carburetor fittings and gaskets	3T	C					
10	Drain carburetor bowls	3T	C					
11	Drain oil sumps	3T	C					
12	Change spark plugs	3T	C					
13	All engine nuts for tightness and safety	3T	C					
14	Operation and travel of all engine controls	3T	C					
15	Cylinder base nuts (visually)	3T	C					
16	Oil in L. Qts. R. Qts.	3T	C					
17	Oil drained L. Qts. R. Qts.	3T	C					
18	Primers and connections for leaks	3T	CI					
19	Engine mounts	3T	I					
20	Engine mount bolts and shocks	3T	I					
21	Exhaust ring and tail pipe	3T	I					
22	Exhaust pipes and gaskets	3T	I					
23	Intake pipes and gaskets	3T	I					
24	Oil radiator and brackets	3T	I					
25	All lines forward of firewall	3T	I					
26	Installation of all engine controls	3T	I					
27	P. & W. oil temp, regulator	3T	I					
28	Oil tank	3T	I					
29	Hydraulic gear pumps	3T	I					
30	Propeller governors	3T	I					
32	Cowl leather, felt and pads	3T	I					
33	Cowl for cracks	3T	I					
34	Cowl supports	3T	I					
35	Cowl for fit	3T	I					
	LANDING GEAR & HYDRAULIC SYSTEM							
50	Air in L. G. and T. W. tires	3T	C					
51	L. G. and T. W. Strut height	3T	C					
52	L. G. latch—lube	3T	C					
53	L. G. and T. W. fittings—lube	3T	C					
54	Tail lock mechanism—lube	3T	C					
55	Fwd. and rear bungee fittings—lube—oil	3T	C					
56	Hydraulic fluid supply reservoir	3T	C					
57	Set parking brakes—check for leaks	3T	I					
57A	Hydraulic panel control valves	3T	I					

BASE.—(*Continued*)

Item No.	Operation	DC-3 DST	I C	Mechanic Left	Mechanic Right	Note	Inspector Left	Inspector Right
58	Spherical pressure tank	3T	I					
59	Ret. strut and brake flex. lines	3T	I					
61	L. G. and T. W. tires	3T	I					
62	L. G. fittings and bolts	3T	I					
63	Brake torque	3T	I					
64	L. G. upper truss	3T	I					
65	Bungee fittings	3T	I					
66	Bungee cords	3T	I					
67	Tail spindle assy.	3T	I					
68	L. G. latches	3T	IC					
70	L. G. safety pins for binding	3T	I					
	HEATING & VENTILATING SYSTEM							
81	Fill complete heating system (outside air permitting)—check for leaks	3T	I C					
82	System filled to correct level	3T	C					
83	Clean heat control screen	3T	C					
84	Manual heat control and nose valve	3T	I					
85	Thermometers	3T	I					
86	Steam and water lines	3T	I					
	ELECTRICAL SYSTEM							
90	Check battery________Battery changed______	3T	C					
91	All lights	3T	C					
92	Pitot heater	3T	C					
93	L. G. signals	3T	C					
94	Throttle switch and L. G. horn	3T	C					
95	Fuel-pressure switch setting	3T	C					
96	Seat-belt sign	3T	C					
97	Steward and cabin signals	3T	C					
98	Governor hydromatic switch	3T	C					
99	Gas-tank selector switch	3T	C					
[illegible]	[illegible]	3T	C					
[illegible]	[illegible]	3T	C					
103	Wing, windshield, and prop de-icer motors	3T	C					
104	Clean bat. compt., contacts, and ground bat. contacts	3T	C					
105	Thermocouple conn. and wires	3T	C					
110	Master switch	3T	C					
111	Solenoid switch	3T	C					
112	Mixture analyzer sample line and nipples	3T	C					
114	Tach magneto mountings	3T	I					
115	Ignition harness and terminals	3T	I					
116	Conduits for chafing	3T	I					
117	All engine conduits	3T	I					
118	Starter and generator leads and brackets	3T	I					
119	Booster leads and mountings	3T	I					

BASE.—(*Continued*)

Item No.	Operation	DC-3 DST	I C	Mechanic Left	Mechanic Right	Note	Inspector Left	Inspector Right
	INSTRUMENTS							
130	Instruments reported by pilot	3T	C					
131	Instrument lines	3T	C					
132	Instruments—zero setting	3T	C					
133	Clean and adjust regulator valve (turn and bank)	3T	C					
134	Replace filters, Sperry inst.	3T	C					
135	Clean glasses on all instruments	3T	C					
136	Barograph mountings and connections	3T	C					
137	Clean Pitot-static tubes	3T	C					
	WINGS & FUSELAGE							
150	Clean under all flooring removed	3T	C					
151	Wing butt fittings	3T	I					
152	Spars and ribs	3T	I					
153	Weather stripping	3T	I					
154	Paint and insignia	3T	I					
155	All glass windows	3T	I					
156	Condition of stringers	3T	I					
157	Condition of bulkheads	3T	I					
158	All cargo compts. and flooring	3T	I					
160	Skin—inside and outside	3T	I					
161	Wing fillets—open inspec. plates	3T	I					
162	Wing trailing edge ribs	3T	I					
163	Toilet container compt.	3T	I					
164	Wing butt fairing—bolts and flanges	3T	CI					
	CONTROL SURFACES							
180	Open all surface-control inspection doors	3T	C					
181	Remove flooring necessary to inspect control cables	3T	C					
182	Operation & adjustment of wing flaps	3T	C					
185	Wing flaps and operating mechanism	3T	I					
186	Ailerons, hinges, and flettner	3T	I					
187	Aileron and flettner control cables, bell cranks, fittings, pulleys, and fair-leads	3T	I					
188	Rudder, hinges, and flettner	3T	I					
189	Rudder travel	3T	CI					
190	Rudder stop cables	3T	I					
191	Rudder horn	3T	I					
192	Rudder and flettner control cables, bell cranks, fittings, pulleys, and fair-leads	3T	I					
193	Elevator, hinges, and flettner	3T	I					
194	Elevator horn	3T	I					

BASE.—(*Continued*)

Item No.	Operation	DC-3 DST	I C	Mechanic Left	Mechanic Right	Note	Inspector Left	Inspector Right
195	Elevator and flettner control cables, bell cranks, fittings, pulleys and fair-leads	3T	I					
196	Horizontal and vertical stabilizer skin	3T	I					
	PROPELLERS							
221	Hubs and blades	3T	I					
222	Slinger rings	3T	I					
	DE-ICERS							
231	Prop. de-icer fluid supply	3T	C					
232	Carb. and windshield alcohol supply	3T	C					
233	Drain de-icer line sumps	3T	C					
236	De-icer surfaces	3T	I					
237	Carb. and windshield de-icer hand pump	3T	I					
	COCKPIT							
250	Remove flooring for inspection	3T	C					
251	Clean under flooring	3T	C					
257	Seats, supports, and mechanism	3T	I					
258	Windshield glasses	3T	I					
259	Control-wheel supports and fittings	3T	I					
260	Rudder pedal supports and fittings	3T	I					
261	Emerg. exit doors and fittings	3T	I					
262	Flooring	3T	I					
261	Operation of all controls	3T	I					
264	Flare-release controls	3T	CI					
265	Aileron control chains	3T	I					
266	Cockpit to cabin door	3T	I					
267	Check operation of all control surfaces	3T	CI					
268	Nose—interior	3T	I					
	CABIN—BUFFET & TOILET							
280	All chairs and mechanism	3T	I					
281	Buffet and stationary buffet equip.	3T	I					
282	Toilet and stationary toilet equip.	3T	I					
283	Airsickness container brackets	3T	I					
284	Footrest	3T	I					
285	Emergency-door control	3T	I					
286	Cold air vents (psgr)	3T	I					
287	Cabin upholstery and fabric	3T	I					
288	Doors and locks	3T	I					
289	Weigh hand fire ext. (cabin and cockpit)	3T	C					
290	Oxygen pressure	3T	I					
291	Oxygen equipment and lines	3T	I					

This form has been properly executed____ Mechanic ____ Inspector

constant supervision of competent men. The safety education of maintenance personnel has reduced accidents to a minimum by requiring each mechanic to observe all safety rules established by the Federal government and the air lines. It is the individual's responsibility to see that he performs each operation with the utmost precision, whether it is inflating a tire or doing a major overhaul job on a power plant. The supervisor's instructions should always be followed, for his knowledge has been gained by previous experience along these lines.

Time will not permit the listing of all parts of an airplane that require extreme care with regard to safety; however, some of the major ones are listed below.

Signaling Devices.—These comprise flares, Very pistols, and other methods of signaling. Since these items contain high explosives, they require infinite care in handling. Although they are seldom used, when they *are* used it is imperative that they be in perfect operating condition. All signaling devices should be carefully checked at each inspection period to be sure that they are in working order.

Propellers.—A propeller should *never* be rotated either by hand or by starter without first making sure that the *ignition switches are off*, that all obstacles are cleared away from the propeller, and that the *fuel is off*. Many permanent injuries and fatalities are caused by the careless rotation of propellers.

Landing Gear.—Since present-day aircraft employs retractable landing gear for greater efficiency, extra care must be exercised in working on or around any part of the landing-gear retracting mechanism, for the operation of any of these levers might lower the ship, crushing personnel and equipment and damaging the ship. No student is to operate any landing-gear mechanism or any similar mechanism without having received previous instructions upon its operation and without a direct order from and under the supervision of his supervisor.

Tires.—No student or mechanic should attempt to inflate tires to their proper capacity before installation of the tire on the gear itself. Many persons have received permanent injuries to their faces, bodies, and arms as a result of bursting tires. The hazard is due to the fact that the component parts are not structurally strong enough to withstand the stress individually; they are sufficiently strong only when combined as a unit.

Oleo.—Landing-gear or tail-wheel oleos should never be deflated by removal of the filler plug. All air pressure should first be removed by compressing the valve core installed for that purpose. If the threads of the filler plug are partly damaged, serious injury can be received if the plug is removed first.

Smoking.—No smoking is permitted at any time within an enclosed area or in the vicinity of an airplane. There are a number of highly inflammable materials used in the structure as well as in the operation and maintenance of aircraft; therefore, very rigid rules regarding smoking and the mixing of combustible fluids in closed areas or in the vicinity of aircraft are enforced.

There are many inherent dangers in the aircraft field of which the average person, strange to the industry, has no knowledge. Students must bear in mind that all the safety rules set up by the operators and by the government are for their own safety as well as for the safety of others. Therefore, these rules must be observed to the letter. Fire caused by the careless use of matches or by smoking may result in self-destruction.

Grounding Precaution.—Grounding precautions are necessary to dissipate static electricity, which is generated by the friction of gasoline through the hose, by the friction of air across the plane, and by friction caused by contact with various types of material. Therefore, the grounding precautions set up by each air line must be adhered to before drawing off any tank of gasoline, oil, etc. Because of its rubber supports, an airplane is almost perfectly insulated from the ground.

Jack, or Lifting, Points.—An aircraft should never be lifted at any point other than that specified by the manufacturer or the operator. No student or mechanic should walk on a plane except at those points indicated as a cat walk. To the person unfamiliar with airplanes, a scratch may seem very slight, but scratches caused by nails in shoes or by any other article harder than the material of the plane can develop into disastrous troubles. Vibration of the plane may cause it to break down at the point where scratches appear, causing failure of the part.

Ladders and Miscellaneous Equipment.—Inexperienced mechanics have caused much damage to equipment and also severe injury to personnel by careless housekeeping, *i.e.*, by leaving rivets on the floor or oil on the floor or on ladders or work stands. An aircraft mechanic is expected to set and maintain a high

standard of cleanliness around the shop and the workbench, as well as with respect to his person. At all times he should wear clean clothes and should keep the shop and the area just as clean as possible. He should never leave coiled hose, coiled electric wire, oily rags, plugged-in soldering irons, etc., where they may cause injury. All equipment must be kept in its proper place.

Locking Devices.—The mechanic should always take extra care to see that the correct safety device is used in the correct manner. He should handle all cotter pins, safety wire, Palnuts, and other safety devices in such a manner that they do not fall into any part of the operating mechanisms of the aircraft, possibly to cause serious accidents later on.

The procedure concerning these various safety devices will be taught at the proper point in this course.

"Monkey Business."—Aircraft maintenance is a very serious business and is no place for "monkey business" or horseplay.

The fire regulations set down by the department head must be strictly observed.

Personal Habits.—The air lines will not attempt to regulate the social life of any of its employees or its students unless an individual's personal habits interfere with the proper performance of any of the duties assigned to him. In that case, each company reserves the right to take whatever steps may seem necessary in the interests of the company and the safe operation of its aircraft.

CHAPTER I

SKETCHING AND BLUEPRINT READING

GENERAL

This chapter is not designed to produce a finished draftsman. However, every mechanic must have a working knowledge of and be able to make instrument or freehand sketches, read aircraft blueprints, and lay out simple geometrical figures.

Just as words express the ideas of an author, drawings and sketches express the ideas of a mechanic or a designer. Though an object might be described in words, should it be very complicated it would be almost impossible to describe it completely enough for a mechanic or a machinist to construct it. To save time and to eliminate any possible chance of error, the art of mechanical drafting was invented. It is a language all its own—the language of the mechanic. It so completely describes the object in picture form that the object can easily be manufactured without any possible chance of error. This art not only portrays all the outward appearances of the object but also describes completely the structure of the inside parts, which are not visible to the eye.

Such drawings are made in two ways, freehand and with the aid of instruments. The freehand drawings, or sketches, as they are sometimes called, are made on ruled paper—ruled in squares. These squares are helpful in laying out the lines for direction, as well as in respect to dimensions. Sketches not only are quicker to produce than instrument drawings, but they also make it easier to find and correct all mistakes. From the corrected sketch the final instrument drawing is produced.

The instruments most frequently used for mechanical drawing are drawing board, T-square, 30°-60° triangle, 45° triangle, curves, compasses, dividers, and scales. Very complete and expensive sets can be bought but are unnecessary for the work in this chapter. A small and inexpensive T-square, drawing board, 30°-60° triangle, 45° triangle, one common curve, one

medium-sized compass, one ruler, two pencils (a 3H and an HB), and a soft eraser are all that is necessary.

All drawings are made on either a soft yellow paper or a very thin white paper. If ink tracings are to be made or if no blue-

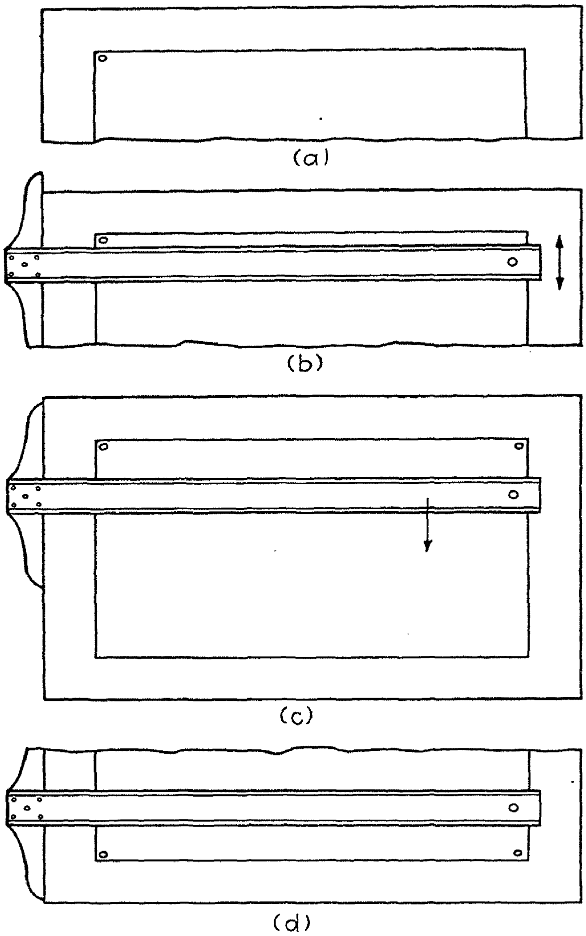


FIG. 1.—Attaching your paper to the drawing board.

prints are necessary, yellow paper is used. If blueprints are to be made directly from drawings, the thin white paper is used.

The paper is fastened to the board by means of a thumbtack or masking tape at the top left corner (Fig. 1*a*). The T-square is placed along the left side of the drawing board with the top edge along the top edge of the sheet of paper. With the head

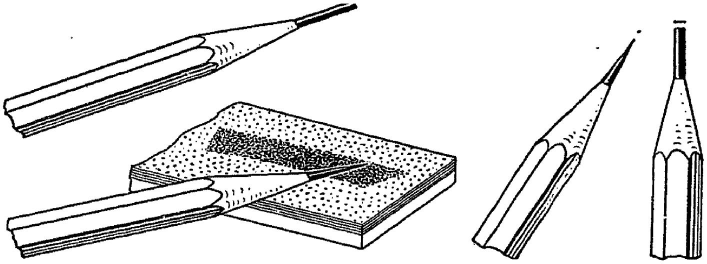


FIG. 2.—Sharpening the pencil.

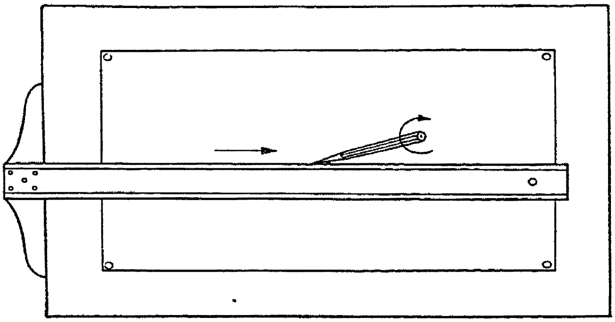


FIG. 3.—To keep the tapered pencil sharp, rotate it slowly as you draw.

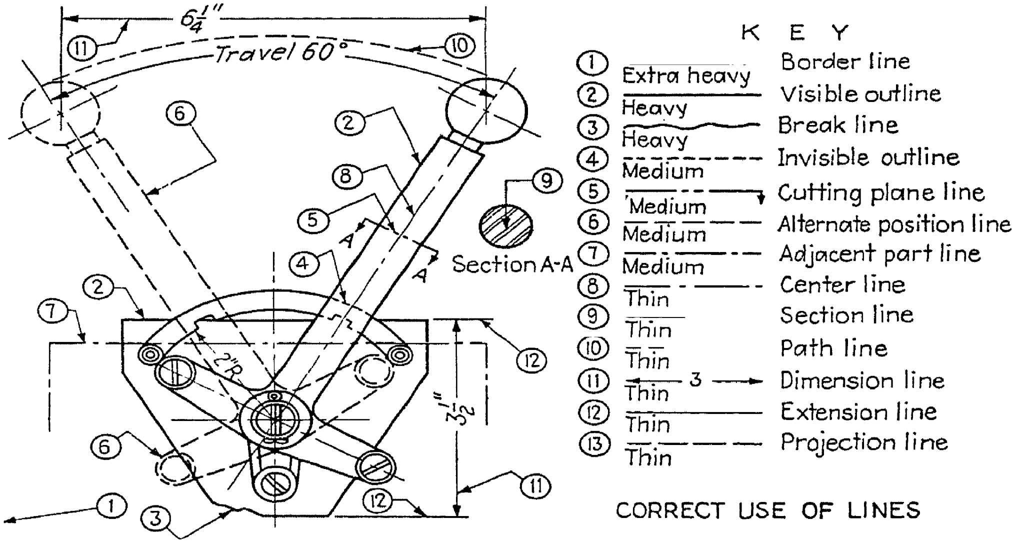


FIG. 4.—Correct use of lines, as authorized by the U.S. Army Air Forces.

of the T-square tightly against the side of the board, the paper is moved up and down until the top edge lines up with the T-square (Fig. 1*b*). All wrinkles are removed, and the top right corner is fastened (Fig. 1*c*). The T-square is now brought

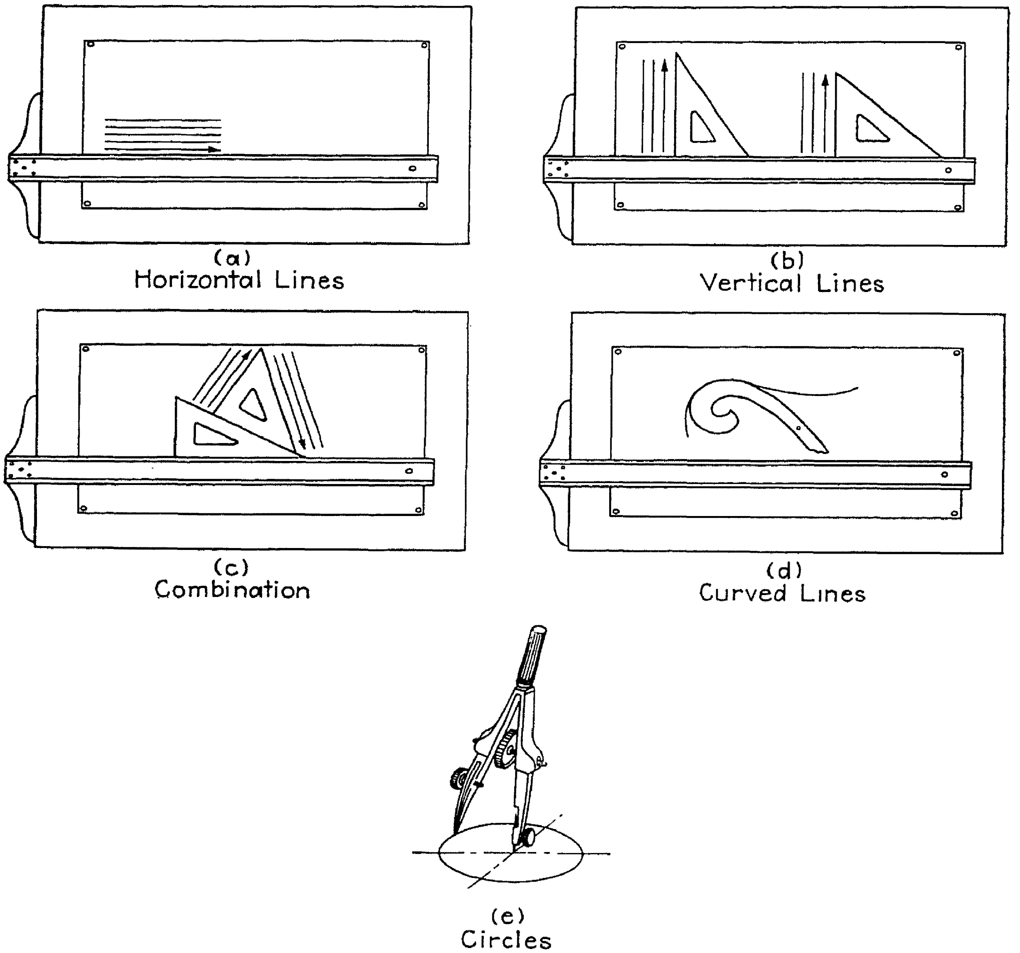


FIG. 5.—Methods of drawing lines.

down the edge of the board across the paper to remove the wrinkles, and the two bottom corners are then fastened (Fig. 1*d*).

The pencil may be sharpened in two ways, either with a chisel point or with a sharp point. Whichever type of point is preferred may be used. If the chisel point is not used carefully,

the line will vary in width, giving a very poor drawing. The pencil is sharpened by cutting the wood away in long slopes, but the lead is cut by rubbing the point on a sandpaper block (Fig. 2). If the point is a long taper, it may be kept sharpened by rotating the pencil when the lines are being drawn (Fig. 3).

In Fig. 4 a sample of different types of line is given. These are the correct lines as given by the United States Army Air Forces. They will be explained more in detail later.

Horizontal lines are drawn with the upper edge of the T-square laid as a guide. The lower edge of the blade should never be used (Fig. 5*a*). Vertical lines are made by placing a triangle against the upper edge of the T-square and drawing along the vertical edge of the triangle (Fig. 5*b*). It is easier to draw from left to right and from bottom to top when these instruments are used. Lines making angles of different degrees with the horizontal or vertical are drawn with different triangle–T-square combinations (Fig. 5*c*). Curve lines, other than perfect circles, are made by arcs of different circles or by the use of mechanical curves (Fig. 5*d*). Small and large circles are made with small and large compasses (Fig. 5*e*).

FIG. 6.—Mechanical scale.

Measurements are made with a scale or ruler (Fig. 6). If a number of measurements are to be made the same, a pair of dividers may be set at this measurement and thus the constant moving back and forth of a ruler will be eliminated.

PRINTING

Notes, figures, and letters are used to describe and dimension drawings. These notes also tell the materials or the number of articles required. Letters are made in two different forms, as capitals and small letters. They can be made either perpendicular or at a 30° slant. Because handwriting is usually approximately at a 30° slant, it is much easier to print at the same angle. Also, since hand printing is never perfect, the angle of slant will vary. This variation is less noticeable in a 30° slanted letter than in a perpendicular letter. For this reason only the 30° slanted letters are shown in Fig. 7. This figure shows capital and small letters, as well as figures. The same principles are used to lay out the perpendicular letter (see Fig. 8).

The bodies of the small letters are two-thirds the height of the capitals, with the ascending lines and the descending lines one-third more above or below. Ascending and descending lines are the straight lines of a "b" or a "p," for example. Small letters are formed by laying them out in the same manner as the capitals. They are likewise a combination of straight and curved lines. A sample is also shown in Fig. 7.

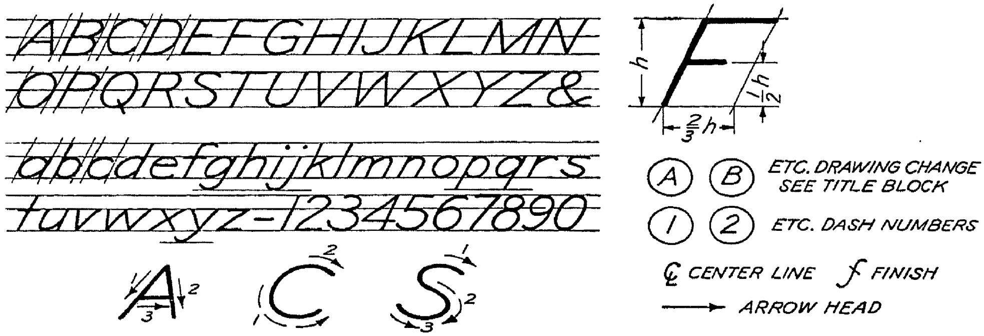


FIG. 7.—Sample letters (slanted).

A sample of numbers is likewise given in Fig. 7. They are also, for the main part, a combination of straight and curved lines.

Both the zero and the "0" are ellipses. The parallelogram used as a guide for laying out the "0" is marked in the center of the top, the base, and the sides. By joining these center marks, a nice uniform "0" or zero is made. All round letters are a

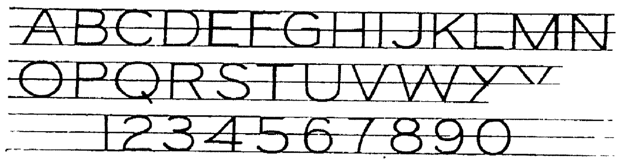


FIG. 8.—Vertical letters and numbers.

portion of the "0" and are formed by laying out in the same manner. If the letter is a combination of round and straight lines, it is generally true that the straight line is merely attached to a part or a section of an "0." In practicing the formation and proportions of letters, it is best to lay them out as suggested above. After the general proportions have been learned, it is not necessary to continue this practice; but should any letter

prove to be difficult, it should be resumed until the letter is mastered.

PROJECTION OF THE DRAWING

If an artist draws a picture of an object, he draws it as it appears, not as it really is. The mechanic, inventor, or designer, however, must visualize, or see clearly in his mind's eye, exactly what the object looks like and draw it as it really is. He must also be able to draw it by means of a few lines properly placed on paper so that it can be accurately made from that drawing.

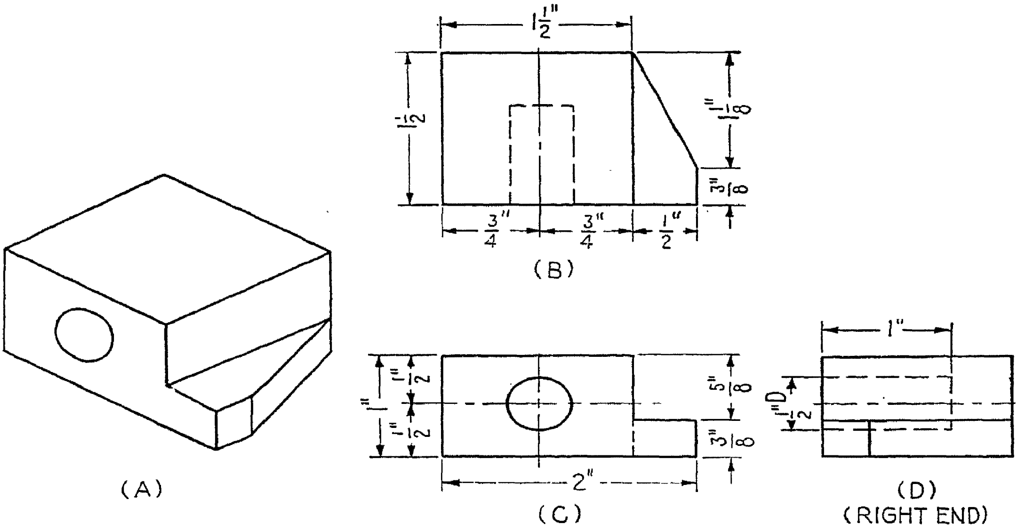


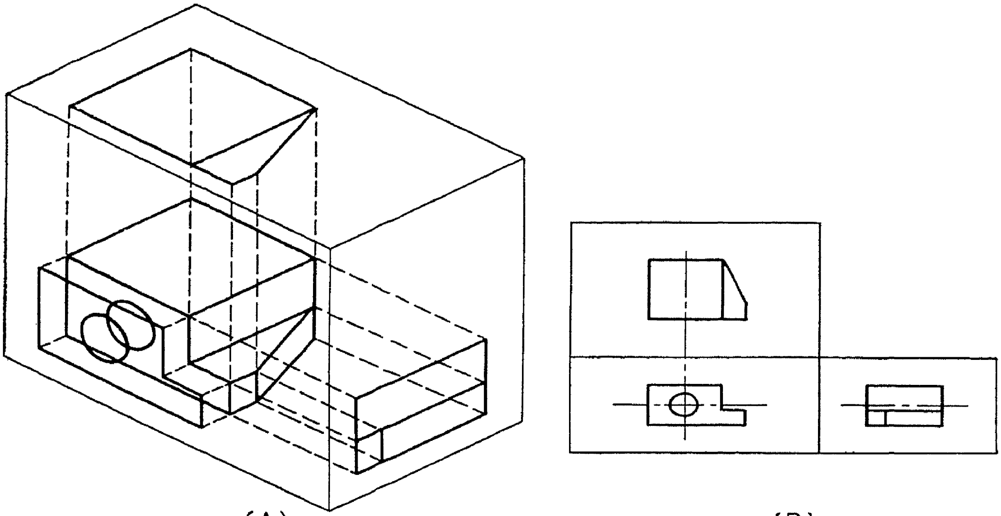
Fig. 9.—Small block.

Flat surfaces are called *flat planes*, and curved surfaces are called *curved planes*. The intersection of any combination of these planes must give either a straight line or a curved line, depending on the way in which the planes intersect. As stated above, a drawing is a group of lines properly placed on paper. But, further, a drawing is the proper placing on paper of lines that represent the intersection of surfaces or planes. All intersections must be shown in some way. These intersections can be shown by means either of full or of dotted lines. The proper use of these will be discussed later.

Part *A*, Fig. 9, gives the artist's conception of how the object looks. In this drawing the hole is an ellipse, the rectangular top is a parallelogram, and the depth of the hole is not given. In

order to show these correctly, it is necessary to draw the object in a series of views that will show everything about the block. These views must be so arranged as to show clearly what part of the block they represent. Three views are generally used, the top, the front, and the right side view. Sometimes, in complicated drawings, an auxiliary view is necessary, but not usually in simple drawings.

Consider that you have a square transparent box with the bottom cut out. Place this on top of a block, as shown in Fig. 10.



(A) (B)

FIG. 10.—(*A*) projection of the block to the faces of the glass box, (*B*) the glass box opened out flat. For simplicity the dotted lines for the hole have been omitted.

If you stood directly above the object and drew on the top surface exactly what you saw, you would draw the top view. With the exception of dimensions and dotted lines, this will look like part *B*, Fig. 9. This view gives length of part, width of part, location of notch, and angle of cut at right end.

If you sat directly in front of the block and drew exactly what you saw, you would draw the front view. With the exception of the dotted line, you would have a figure like part *C*, Fig. 9. This view gives the height of the block, location of hole, and depth of cut of notch.

If you sat directly in front of the right end of the block (marked on figure) and drew what you saw, you would be drawing the right

end view. This, with the exception of the dotted lines, would look like part *D*, Fig. 9.

Part *A*, Fig. 10, shows all three of these views drawn on the correct sides of the glass box. Part *B* shows the glass box after it has been opened up. By inspection it can be seen that it is exactly the same as the three views in Fig. 9, except that the dotted lines and dimensions have been omitted. This is called *orthographic projection.*

So far all dotted lines have been omitted. This is the hardest part to visualize in mechanical drafting; yet, until it is understood clearly, it is impossible to read and understand drawings. Therefore, it should be studied thoroughly so that progress may be as rapid as possible.

Any lines, objects, nuts, bolts, holes, etc., that fall below the outer surface or surfaces you must show by dotted lines. For example, the outer surface of the front of the block in Fig. 9 is the first surface that you touch when facing the front side of the block. This surface has a hole in it. Since it is on the outer surface, the hole is a full line. The top view has two outer surfaces, the top of the block and the top of the notch. If you look down on the top of the block, you do not see the hole; yet you know that it is there by looking at the front view. As a mechanical drawing must show everything, visible or not visible, you must show that hole. Since it falls below the top surface, you must show it in dotted lines. That is why there are dotted lines for the hole in parts *B* and *D*, Fig. 9.

Now the need for all three views can be clearly shown. For example, in Fig. 9, if you drew only parts *B* and *D* you could not tell from the dotted lines whether the hole was a round hole or a square hole. Therefore, the front view is absolutely necessary to show that the hole is round.

Figure 4 shows a set of sample lines. In laying out a drawing, be sure always to make all lines light but clear. This includes dotted lines, dimension lines, etc. If you make the lines light, any mistakes you make you can correct without ruining the appearance of your drawing. If you draw the lines heavy, they cut into the paper and although erased still show when you have completed your drawing. When you have finished making all corrections, return and make all body and dotted lines heavy. This will give a clear-cut blueprint. The body lines are the

outlines of the body, side, top, etc., of the block. Dotted lines are not quite so heavy or so wide as the body lines. The dots should be about the size given in Fig. 4, and uniform. Varying sizes of dots give a drawing an untidy appearance.

Center lines show the location of the center of holes. These lines are much lighter than body lines and consist of a long dash, a dot, etc. The center of a hole is marked by two of these crossing perpendicularly.

Dimension lines give the dimension of the drawing. They, also, are light lines. Figures 4 and 9 show how these are made. Light full lines, called *extension lines,* extend a short distance from the object. These lines do not connect with the object lines. Between these two lines and $\frac{1}{4}$ in. out from the body line is drawn another line parallel to the latter. This is called the *dimension line.* The ends of this line are terminated by neat arrowheads. The dimension line is broken in the center, and the dimension is neatly printed in the break. The symbols for foot (′) and inch (″) follow the last numeral of the dimension. If more than one dimension is drawn on the same body line, they are placed $\frac{1}{4}$ in. from the last line, as shown in Fig. 9.

One of the most important parts of a drawing is the dimensions. All dimensions necessary to make the object must be given so that no time will be lost or error made by the mechanic in measuring the drawing. It is not necessary to repeat any dimension, for this may overload the drawing. Also, whenever possible the placing of dimensions within the outline of a view should be avoided. The space between views can be used to give dimensions, but over-all dimensions should never be placed between the views.

A line of measurements should be complete; *i.e.*, the detail dimensions should be continuous from outside to outside, instead of being scattered (part *B*, Fig. 9). For short dimensions the two parts of the dimension line are so placed that the arrows point inward and the numerals appear between the arrows (part *B*, Fig. 9). For lack of space the numerals are sometimes placed above the dimension lines. If this space is not large enough for numerals, they can be placed at the end of one section of the dimension line. Radii of bend are usually given on the curve surface, while dimensions for holes are given on the side view of the hole except when the diameter is over 2 in.

The student should further impress the above on his memory by studying Fig. 4 and any or all of the blueprints at the end of the chapter.

SIMPLE SKETCHING AND DRAWING

Although not every mechanic is required to be a draftsman, it is absolutely necessary that he be able to represent his ideas with accurate freehand or instrument sketches. This art can be mastered only by practice.

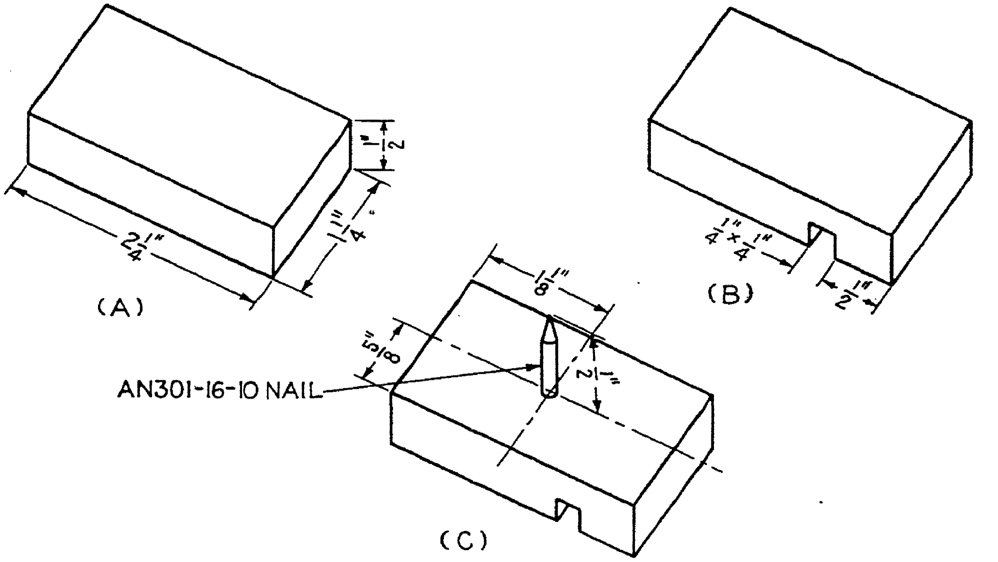


Fig. 11.—Second block.

Sketches are divided into many groups, but the mechanic is interested only in the ones given below:

1. Design sketch—used when working out new ideas.
2. Working sketch—used in place of a working drawing to manufacture.
3. Detail sketch—made from a manufactured part to show all details, including dimensions.
4. Assembly sketch—used to show the relative position of assembled units.

Freehand sketches are made on sketch paper (see Fig. 12). This paper is ruled off in small squares of $\frac{1}{8}$ to $\frac{1}{4}$ in. to help the mechanic make his sketch. It is thus not necessary to have instruments to make the sketch. The straight lines on the paper

act as guidelines for making straight lines and aid in laying off measurements or dimensions by acting as a ruler. Before beginning his sketches each student should obtain some of this paper.

We have now had enough explanation to begin sketching. Let us first take a simple object and work up to harder ones.

The first sketch will be the small wooden block shown in Fig. 11. This block is $2\frac{1}{4}$ in. long, $1\frac{1}{4}$ in. wide, and $\frac{1}{2}$ in. thick. Cut a notch $\frac{1}{4}$ by $\frac{1}{4}$ in. across the bottom right end of the block $\frac{1}{2}$ in. in from the end (see part *B*, Fig. 11). Now drive an AN301-16-10 common iron nail through the center of the block, driving from the bottom side up. The nail should extrude through the block $\frac{1}{2}$ in. The designation AN301-16-10 is a system used by the Army and Navy to describe the nail. This system will be explained later (see Chap. IV).

AN 301-16-10

– $\frac{10}{8}$, or $1\frac{1}{4}$ in. length
in. diameter and
–a common nail, cement coated, of . . .
–Army-Navy designation for . . .

With the block as in part *C*, formulate in your mind an image of the object and how it should look in the three views. Next try to visualize the size and location on your paper. With this in mind, locate either the center line or the corners of the block. Be sure to allow enough space between views to give dimensions. Care must also be taken to center the figure on your sheet. Draw the outline of the block, drawing the vertical lines up and the horizontal lines from left to right. After outlining the object, add the details and dotted lines. Add the dimension lines, arrowheads, dimensions, and notes. Check your sketch. It should look like Fig. 12.

When drawing straight lines, look at the point to which you are going and not at the pencil point. Make lines of short overlapping strokes. If they are wavy, do not worry. Practice will improve your technique.

Circles may be drawn by laying out perpendicular center lines and two intermediate lines (Fig. 13*a*). Lay out the radius on all these lines, and connect the points. Another method is to block off the circle by means of a box (Fig. 13*b*).

Have your sketch corrected and make a finished instrument drawing on a sheet of $8\frac{1}{8}$- by 11-in. drawing paper.

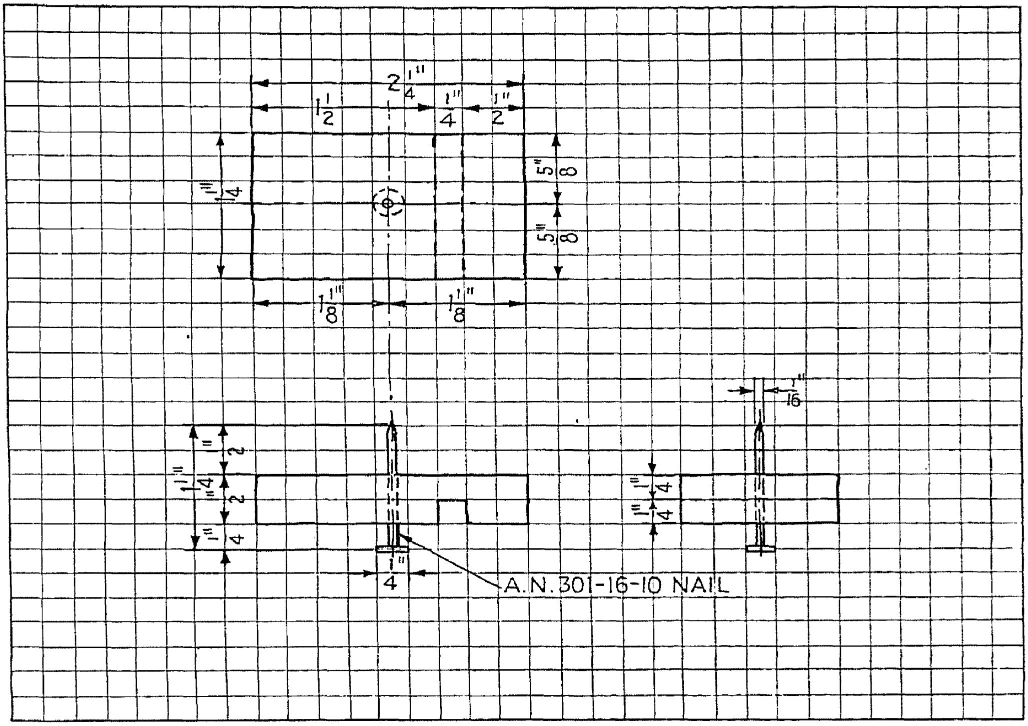


FIG. 12.—Freehand sketch of block of Fig. 11.

So far we have not discussed notes, the bill of materials, or the title, and yet no drawing is complete without these.

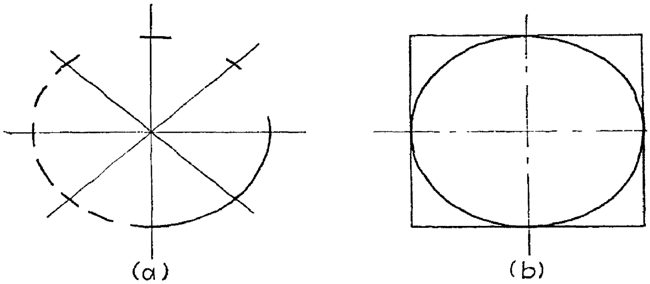


FIG. 13.—Freehand sketching of a circle.

Notes are used to explain or to clarify some object on the drawing and are made as shown in Fig. 14. The bill of materials and the title, in many cases, are incorporated in the same block.

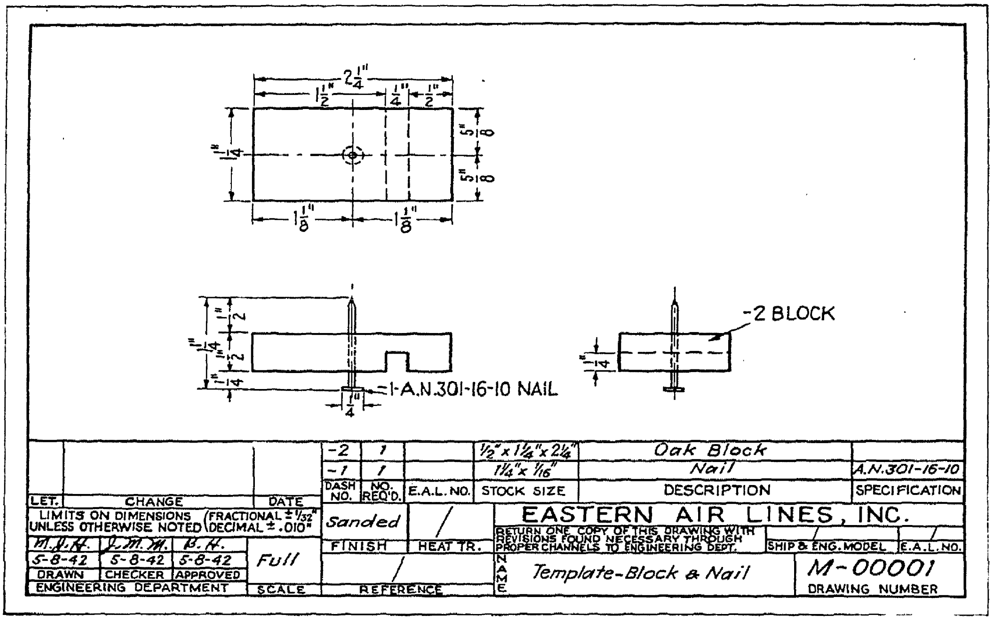


FIG. 14.—Finished instrument drawing of Fig. 11.

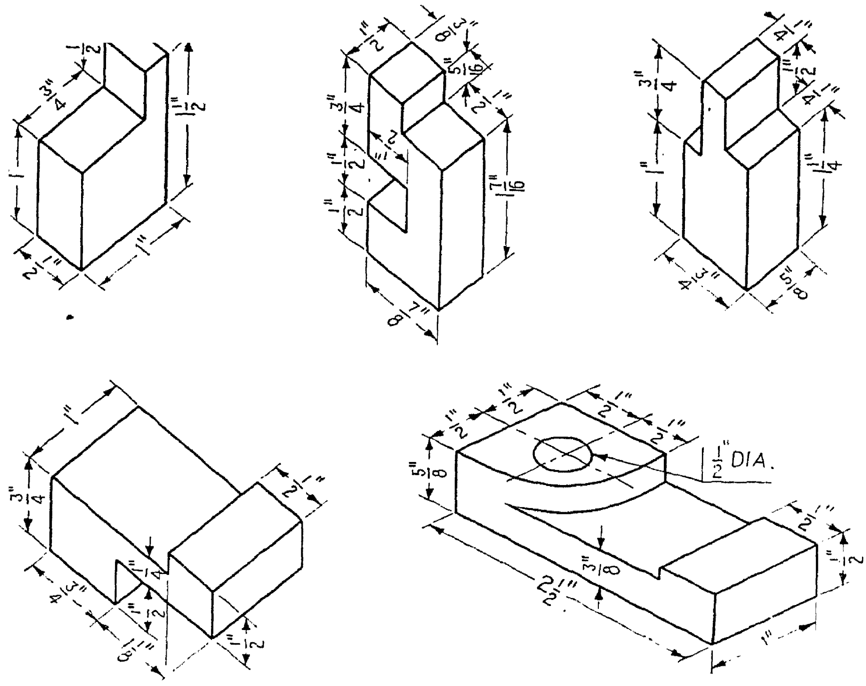


FIG. 15.—Sketching projects.

This has been done at the bottom of your drawing sheet. The title is the name of the drawing; but it must also include a space for the name of the company making the drawing, number of the drawing, the scale of the drawing, the date of the drawing, the name of the man making the drawing, and the name of the man checking the drawing. The bill of materials, whether in the same block or a separate one, must contain a place for the name of the article, the number required, the material, and a description of the article.

When your drawing is complete, fill in the title block at the bottom of the page. The block you drew is of wood; the nail is an AN301-16-10 nail; the name is "Template—Block & Nail"; the drawing number is No. 1. Figure 14 is the final drawing.

Before beginning your advanced drawing, complete sketches and instrument drawings of all three views of all figures given in Fig. 15, including dimensions.

Advanced Drawing

As stated before, details under the surface that cannot be seen are shown by dotted lines. In many cases, however, where the interior is very complicated these dotted lines become very difficult to read. To overcome this difficulty, sectional views are used.

A sectional view is obtained by cutting the object at the point where the detail is located. The front portion is removed, and the detail is exposed. A good example is shown in Fig. 16. The sectional view may be either full section or a quarter view as shown in Fig. 16. A quarter view is where the angle of cut is only 90°.

The cut surface is indicated by cross-hatching, or section lining. Section lines are uniformly spaced lines, generally drawn at a slope of 45°. Any one piece must have the section lines in the same direction; but when two pieces are shown together, they are sectioned in different directions.

In the top view, the position of the cutting plane is indicated by a line (see Fig. 16), but the part supposed to be cut away is not left out.

With the above explanation in mind, begin your more complicated drawing (Fig. 17). The removed section should be the

front top quarter of the round portion only. Make a sketch of the three views, correct the sketch, and make the final drawing.

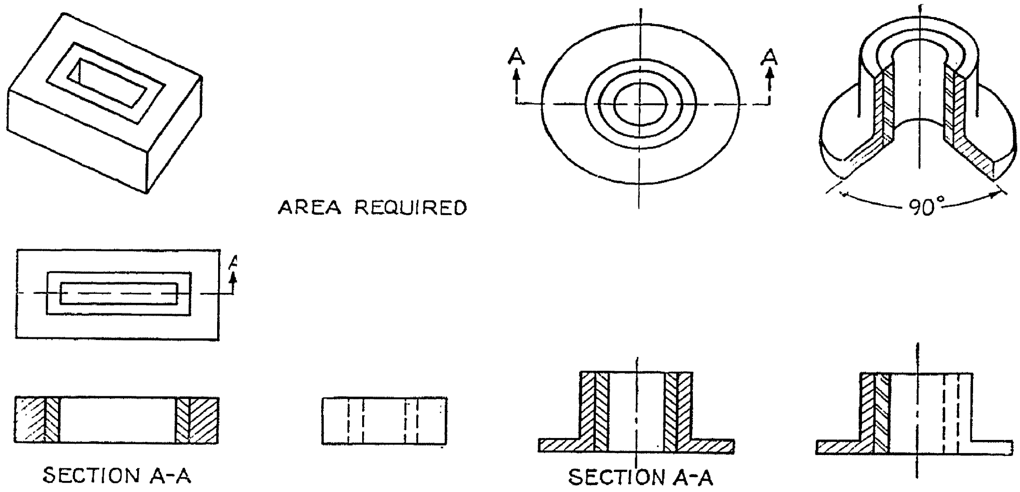


Fig. 16.—Sectional views.

So far we have not discussed how to draw screws, nuts, bolts, etc. This may be done in many ways, depending on the accuracy desired. For the results desired here, the methods covered in

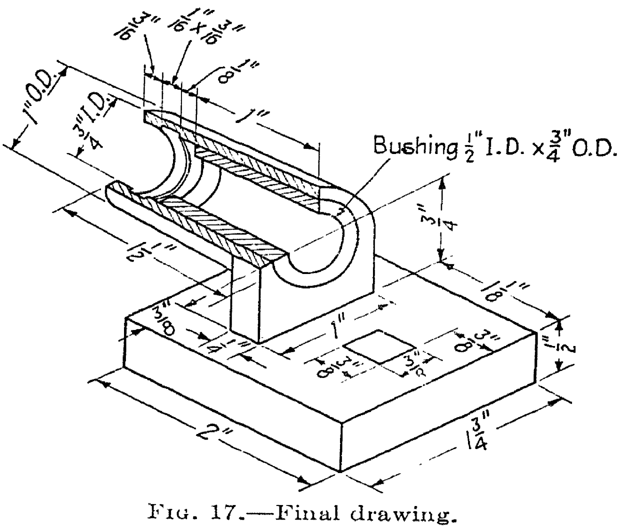


Fig. 17.—Final drawing.

Fig. 18 are sufficient. For additional items refer to Chap. IV, the section on Hardware.

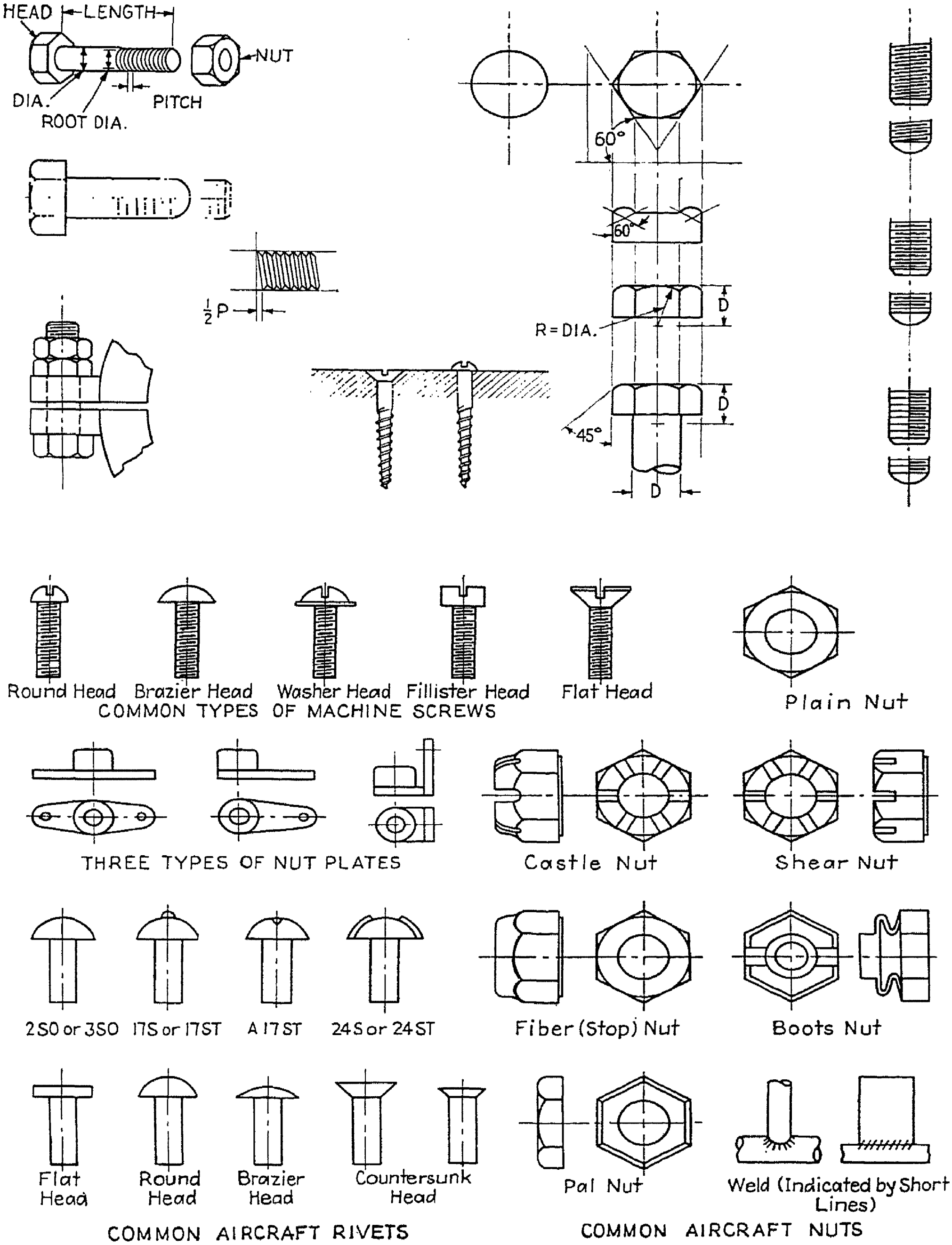


FIG. 18.—Sample threads, bolts, nuts, machine screws, and rivets.

BLUEPRINT READING

It is impossible for the student to have become, in the short time spent on drawings, a first-class draftsman. However, he must know enough about drawing to lay out adequately any job and to read correctly any blueprint that he is given.

We have just finished a drawing of the more complicated type and should by this time have enough general knowledge of drawing to begin a course in blueprint reading.

The term *blueprint* comes from the color of the drawing. Although there are prints of many other colors, blue is the most usual, and therefore all such prints are called blueprints. The only difference in these prints is in the color of the paper or lines, not in the drawings.

If a tool is needed, the designer makes a rough sketch of this tool and passes it on to the draftsman. From the rough sketch the draftsman makes a finished sketch, including all notes and dimensions. The draftsman then places this drawing on yellow paper or on tracing paper. If an ink tracing is desired, it is usually made from the final drawing on tracing cloth or paper. This is then corrected by a "checker." From the tracings, blueprints are made and given to the mechanic. The tracings are filed.

If the blueprint is made in a blueprint box, the translucent tracing is placed against the inside of the glass top, the chemically treated side of blueprint paper is placed against the tracing, and the bottom of the box is closed and clamped tightly into place. When the box is placed in the sun, the blueprint paper slowly turns a light green. This indicates that the print has been exposed enough and must be removed. The print is then washed in water and a fixer, after which it is put out to dry. When the print is being washed, it becomes distorted. Therefore, a drawing should never be measured unless absolutely necessary.

The blueprint paper is a white paper chemically treated. The chemical is soluble in water before exposure to light but becomes insoluble after being exposed to light. Therefore, when the translucent tracing, except for the opaque lines, is placed on the blueprint paper, all parts of this paper become exposed to the light except for the part below the opaque lines, which remains unchanged. When the exposed blueprint is washed in water,

the light-green color becomes blue. The unexposed part that was below the opaque lines washes out clear white. The print is then placed in a fixer to make the blue darker. Although the print has been placed in a fixer, the print will gradually fade if exposed to the sun for any great length of time.

The method just described to develop a blueprint uses the sun to expose the paper. Since sunlight varies greatly from time to time, greatly varied degrees of blueprints are obtained. To overcome this difficulty, complicated machines have been built to ensure having the exact amount of light. The same machine washes the print and fixes it. When the print comes out, it is ready to dry.

A process similar to the blueprint process gives white line prints on a dark-brown ground. These prints are called *Van Dyke prints.* The rays of light are able to penetrate the brown-colored coating, thus making it possible to print with a Van Dyke the same as with a tracing. When this is done, the Van Dyke is called a *negative Van Dyke.* If a print of a Van Dyke is made on Van Dyke paper, the result gives a brown line print on a white ground. This is called a *positive Van Dyke.* Ammonia prints are made like blueprints, except that they are washed in ammonia vapor instead of water. These prints have reddish-brown lines on a white ground.

At the beginning of the course we learned to make three-view drawings of an object. Now we are just working backward. We must take the flat drawing and from that reproduce the object. To read the blueprints correctly and without difficulty, we must be able to reproduce from the working drawing a good mental picture of the object. From the mental picture we must lay out and build the object. Facility in forming these mental pictures comes slowly sometimes. Therefore, if the student does not yet understand the simpler prints, he should spend more time on this subject.

The drawings thus far have all had three views. However, now that the principles are clearly fixed, there may be occasions when one or two views are all that are necessary. For example, the front view is all that is needed in drawing nuts, bolts, and rivets. It is known from experience what the rest of the views would be, so that the object is recognized at a glance. Another example of an irregular drawing is one having a front view

and two end views. The top view is omitted because it is unnecessary.

At the beginning of this discussion the simple method of making the drawings by plane intersection and projection was used. Now a more technical form is necessary. Many drawings cannot be made by merely showing plane intersections. They must be made by point projection.

As has been seen, intersecting planes give lines. Further, intersections of lines give points. For example, in Fig. 19 the

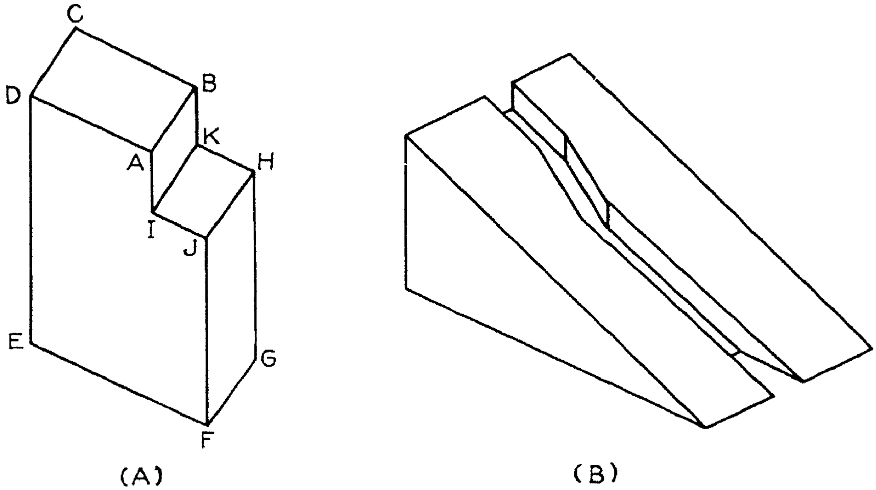


FIG. 19.—Two blocks for point projection.

lines *ab*, *ad*, and *ai* all intersect, forming the point *a*; likewise, all the other points result in the same way.

With part *A*, Fig. 19, we begin point projection.

Place the glass box used for the simple drawing on top of the block. Now draw perpendicular projections of all points to the three faces of the glass box (Fig. 20). Point *a* on the top view is now lettered point a', called *a* prime; point *a* on the front view is now lettered a'', or *a* double prime; and point *a* on the side view is now lettered a''', or *a* triple prime. Since points *a* and *d* are connected on the block, connect points a' and d' on the top view and a'' and d'' on the front view. Likewise, since points *a* and *b* are connected on the block, connect a'' and b'' on the top view and a''' and b''' on the side view. In like manner, connect all other points that are connected on the block on their respective

faces. When you have completed this, all views have been projected, and the dotted lines show the projections.

Cut the box where the top view and the right side view intersect. Obtain Fig. 21 by flattening the box out; this is the same method as that used in the earlier figures.

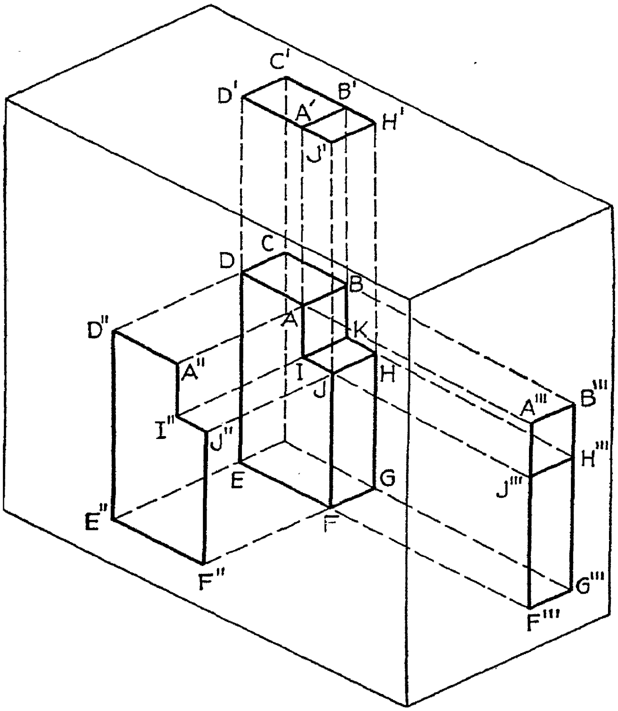


FIG. 20.—Point projection to the faces of the glass box.

At this point the following definitions or statements will be helpful:

1. A point is named by a single letter.

2. A surface is named by stating the letters of the corners in order around the perimeter.

3. An angle is named by giving the sign ∠ and naming the three letters that bound it, as $\angle ABC$. The middle letter always is that of the vertex.

4. When a line is parallel to a plane, the projection of that line on the plane is the true length of the line.

5. If a line is perpendicular to a plane, the projection is a point.

6. When a line is inclined to a plane, the projection of that line is shorter than the line and is said to be "foreshortened."

7. The projection of a straight line is either the true length or less.

8. When a circle is parallel to a plane of projection, its projection will be a circle.

9. When a circle is perpendicular to a plane, its projection on that plane will be a straight line.

10. When a circle is at an angle to a plane of projection, its projection will be an ellipse.

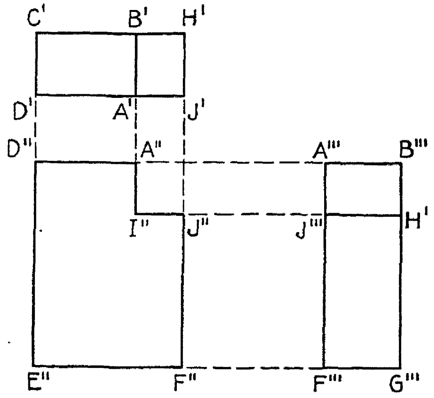


FIG. 21.—Point projection of the block in Fig. 19(*A*).

If the mechanic wished to make the grooved wedge of part *B*, Fig. 19, he would need the dimensions of the wedge. Since the top view and side view do not give true lengths, it is necessary to draw an auxiliary view. This view will be parallel to the grooved plane.

Therefore, it may be said that, whenever it becomes necessary to give dimensions on *any surface or surfaces not parallel to the three conventional views, an auxiliary view should be drawn parallel to the surface to be dimensioned.*

Applying the principles of point projection, we arrive at the drawing in Fig. 22. In this drawing several difficult dotted lines can be seen. By making this drawing by point projection the location of all these lines is greatly facilitated. Since the auxiliary view gives the true lengths of the lines on the wedge side, it is best to give all dimensions of the groove on that view. The height and length of the block should be given on views that show the true height and length as shown in Fig. 22.

The drawings studied thus far have all been one part, but in the shop many of the drawings will be made up of a number of parts. A drawing that shows all these parts fitted together is called an *assembly drawing.* A drawing that shows only one of these parts is called a *detail drawing.* The assembly drawing shows each part in its correct place on the assembled object. Only dimensions that are needed to make the assembly or that cannot be shown on the detail drawings are shown on the assem-

bly drawing. The assembly drawing carries the part number of each object or the drawing number of each object. This facilitates ordering or making the parts. Detail drawings show all details about one part of the assembly drawing. A detail drawing is given to the mechanic making a part. It must contain all dimensions and notes necessary to complete that part.

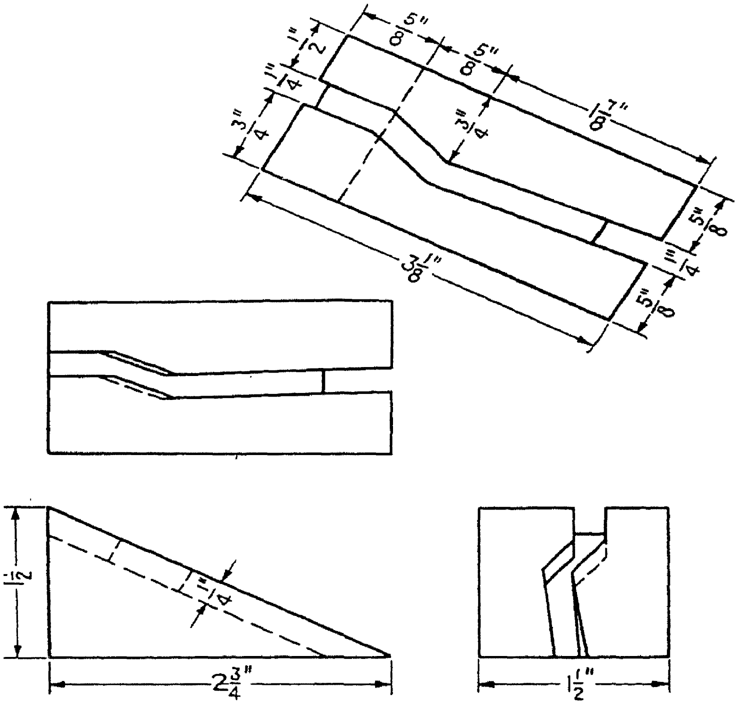


FIG. 22.—Auxiliary view.

With this information in mind, read the following blueprints. Answer all questions after each print.

Questions on Drawing 080786 (Fig. 23):

1. What is the outside diameter?
2. What is the material used? What is the thickness?
3. What size sheet is it made from?
4. What is the size of the lip?
5. What two radii of bend are used?
6. Where is section *AA*?
7. Is there a hole cut in the center?
8. What is the name of the object?

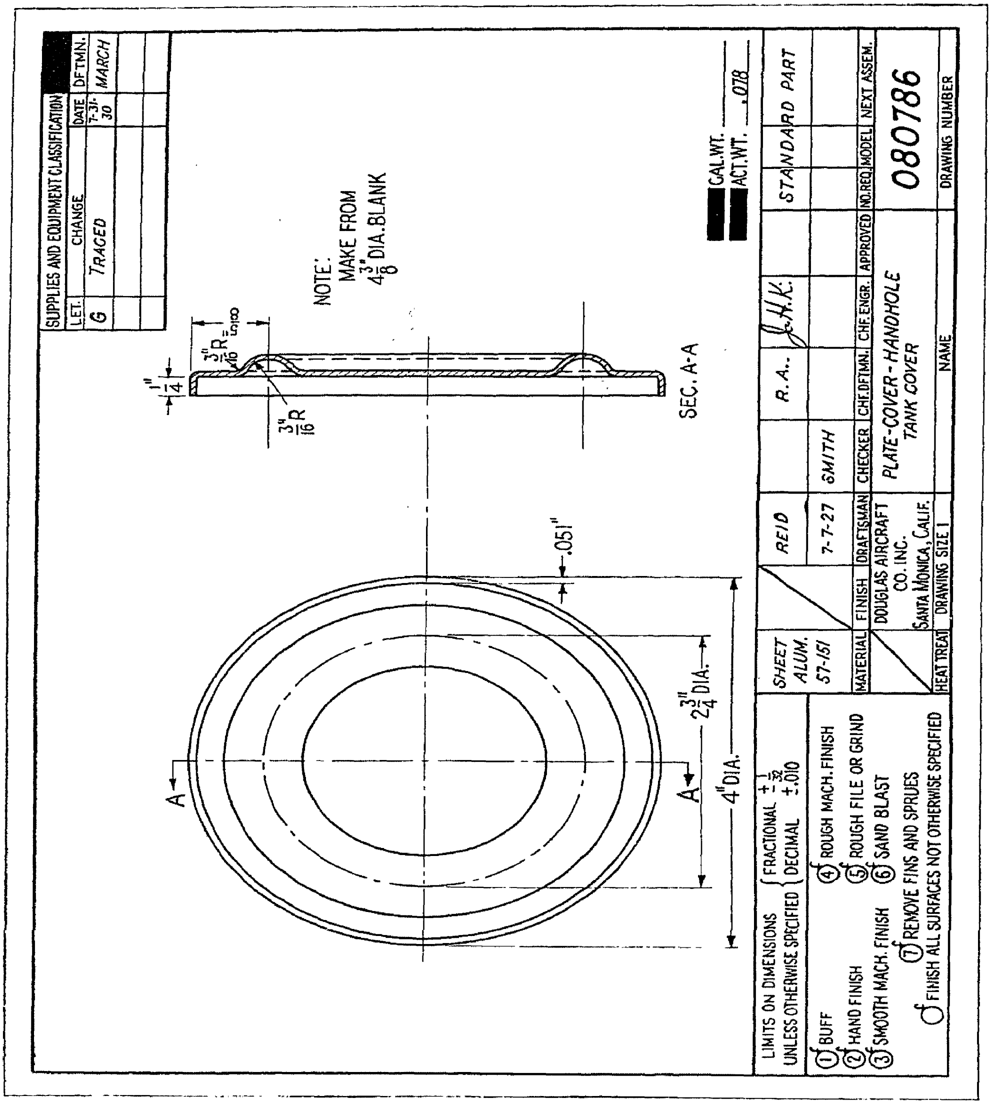


FIG. 23.—Handhole-cover plate.

9. What is the actual weight?
10. What change was made; when; by whom?

Questions on Drawing 132050 (Fig. 24):

1. What material is used?
2. Who is the manufacturer? What planes is it used on?
3. Who checked the drawing?
4. What tolerances are allowed?
5. What is the layout reference?
6. What is the over-all length?

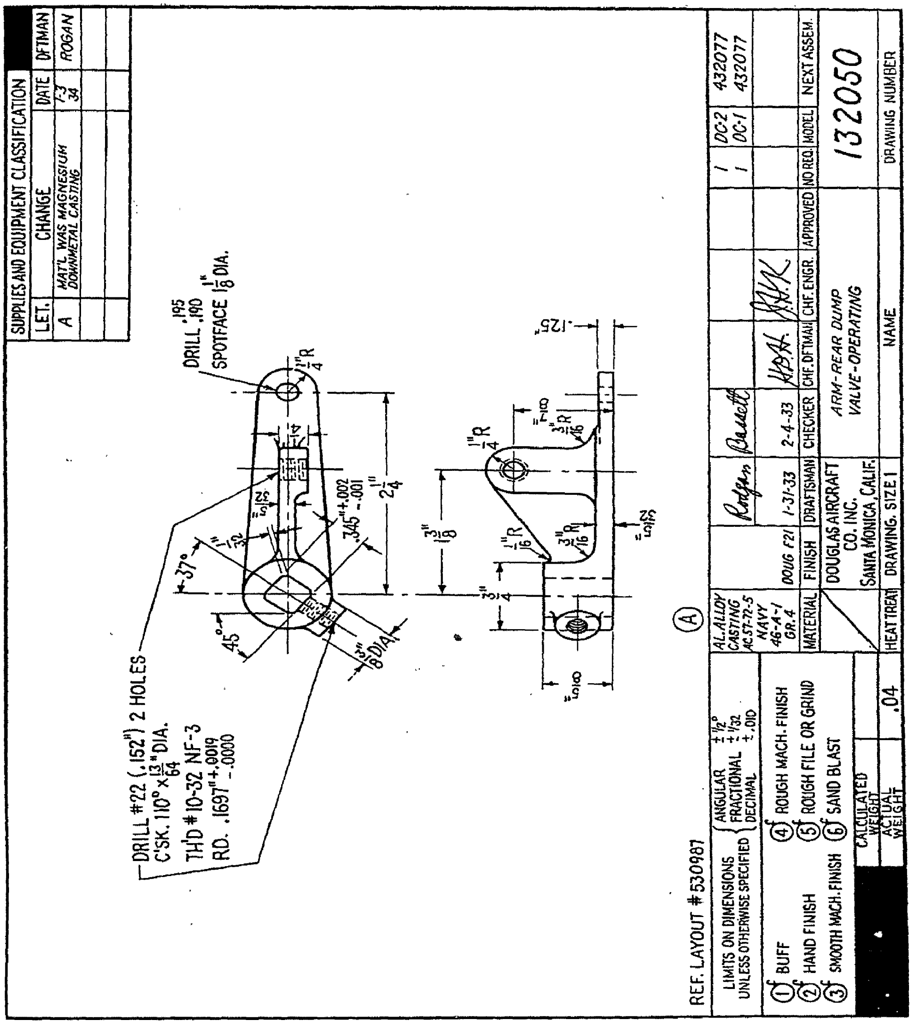


Fig. 24.—Rear dump-valve operating arm.

7. What is the angle that the threaded shoulder makes with the center line?

8. What thread size is used? What is the drill size of the threaded holes?

9. How many different fillet radii are there? List them.

10. What is the maximum radius?

11. What part is spot-faced?

12. What does it weigh?

Questions on Drawing 123565 (Fig. 25):

1. What is the name of the object?

2. Who manufactures it? Who drew it?

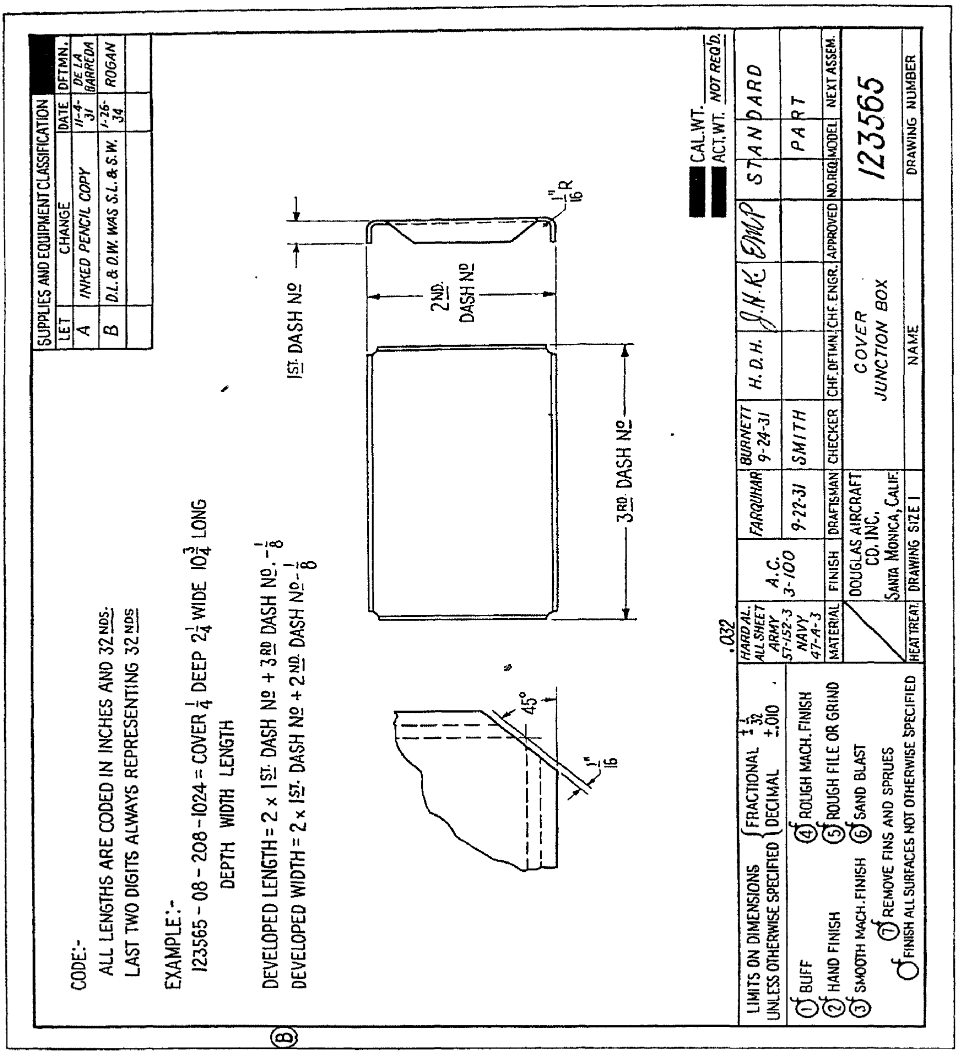


FIG. 25.—Junction box cover.

3. What is the part manufactured from?
4. At what angle are the ends cut?
5. What is the radius of bend on sides and ends?
6. What is the length; the width; the depth?
7. What are the two changes made?

Questions on Drawing 232439 (Fig. 26):

1. What is the name of the object?
2. Where is it located?
3. What material is used to manufacture it?
4. What are the bend radii?

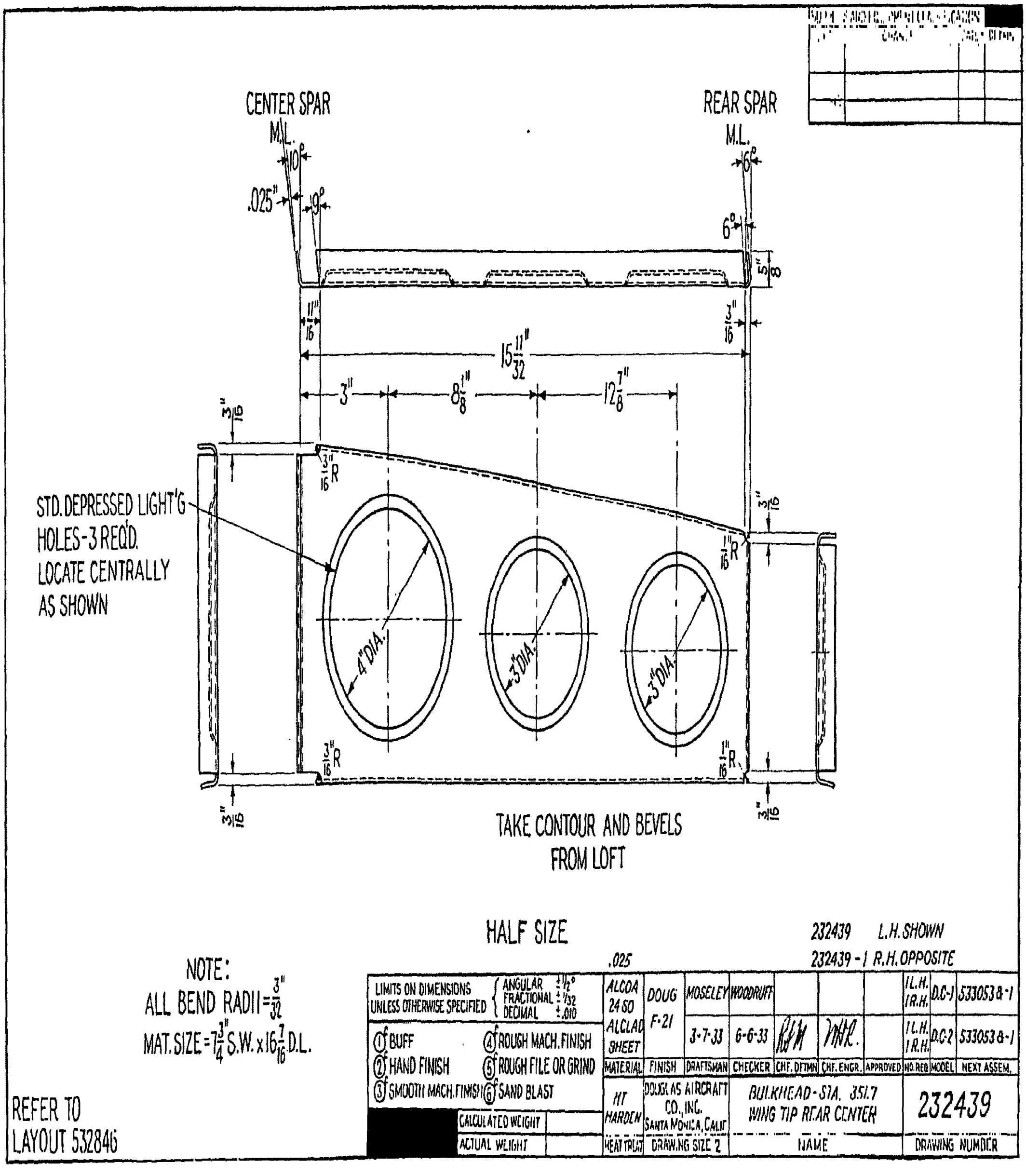


FIG. 26.—Rear bulkhead at rear wing tip.

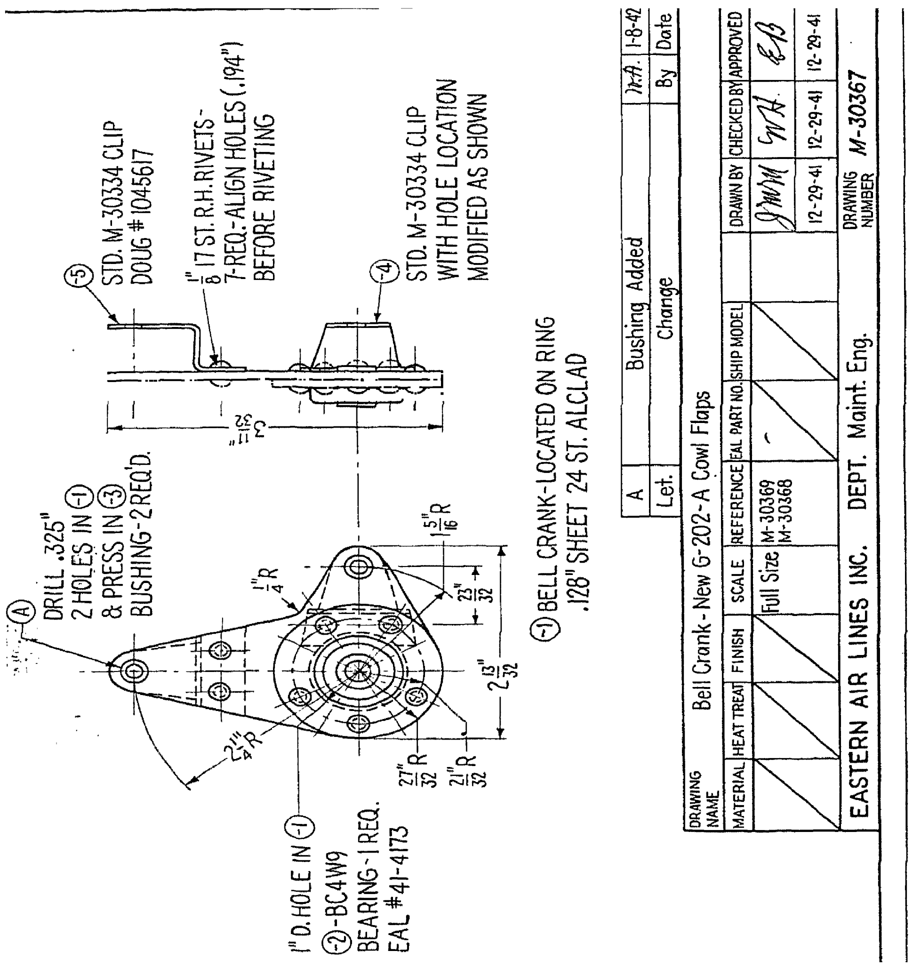


FIG. 27.—G-202-A cowl flap bell crank.

5. What is the material size?
6. How many holes are drilled in the unit? What are their diameters?
7. What are the stop-hole diameters?
8. At what angles are the edges bent?
9. To what is this object attached?
10. Who made the drawing? Who checked the drawing?
11. Is the material heat treated?
12. Are the left and right hand the same? If not, which is shown?
13. Are the lightening holes countersunk?

14. How far apart are the holes located?
15. What is the depth of the flange?
Questions on Fig. 27:
1. What is the diameter of the hole in the bell crank to receive the bearing?
2. What is the (Eastern Air Lines) number for the bearing; the manufacturer's number?
3. What is dash No. 3? How many are required? How is it installed?
4. What is dash No. 4? How does it differ from dash No. 5?
5. What material is used to manufacture dash No. 1?
6. What is the over-all length of the crank?
7. What is the radius (center to center) of the longest arm; of the short arm?
8. What is the outside diameter of bearing?
9. What is used to attach all parts to the bell crank? What are the size and material?

GRAPHIC SOLUTIONS

The study of drawing in the preceding pages has dealt mainly with the making and reading of blueprints and freehand sketches. However, the mechanics of drawing may be used to a great advantage in solving many problems in the aeronautical industry. Some such problems are the graphic solutions used in the layout of sheet metal, metal, and wooden parts. They require a basic knowledge of geometrical construction.

Geometrically, a line may be divided into two equal parts or a perpendicular may be erected at a point in the following way (see Fig. 28): Given line AB, draw, with a radius greater than $\frac{1}{2}AB$, arcs using A and B as the centers. A line drawn through the intersections of the arcs will be perpendicular to AB and will bisect AB.

To bisect angle AOB (Fig. 28), draw arc AB with O as center; using points A and B as centers, draw two arcs with a radius greater than $\frac{1}{2}AB$. Connect the intersection of these two arcs with the vertex O. This line bisects the angle AOB.

To divide the line AB into five equal parts, draw a line from B at any angle (Fig. 28). On this line, lay off five equal spaces of any convenient length. Call the last point C, and connect AC. At each of the other four points, draw parallels to CA. This divides AB into five equal parts.

If it is necessary to move angle AOB (Fig. 28) to some other position, draw line $O'G$ at the new location. Using OC as a

radius and O' as the new vertex, draw an arc. This arc intersects $O'G$ at E. With the distance CD as the radius and E as vertex,

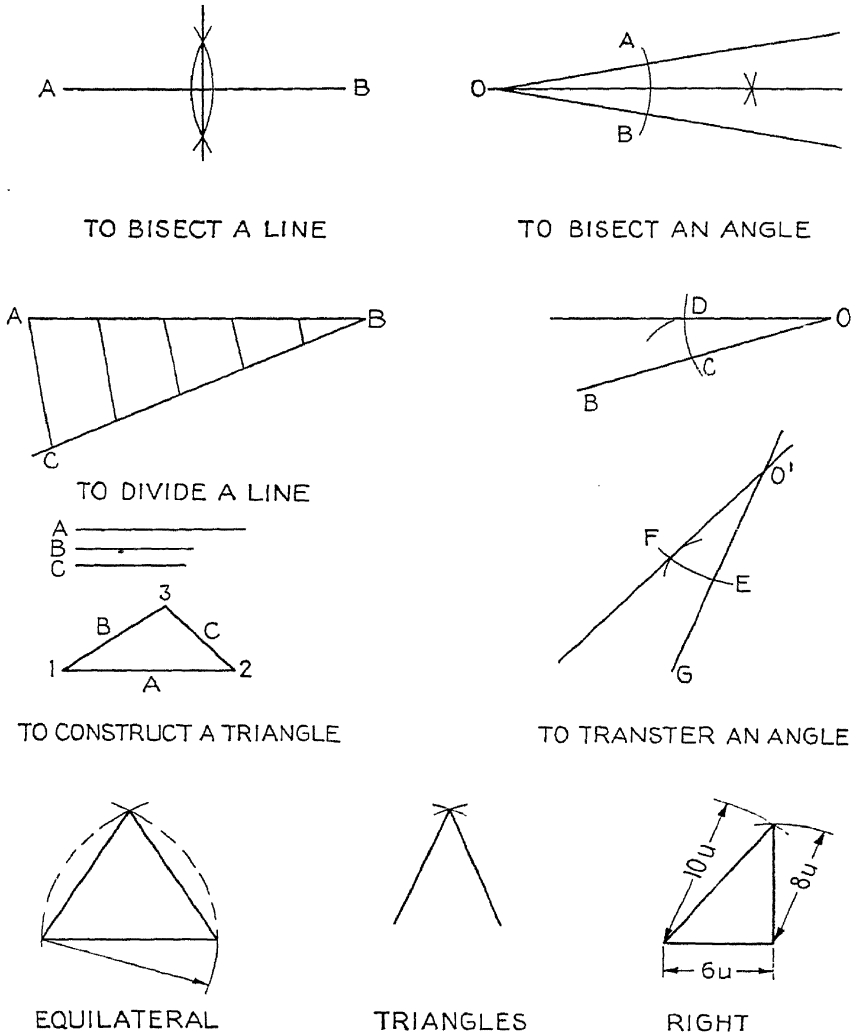


FIG. 28.—Graphic solutions.

draw another arc. Call the point where the two arcs intersect F. Draw line $O'F$ to complete the angle in its new position.

To construct a triangle with three sides given, draw side A in the desired position (Fig. 28). With points 1 and 2 as centers and B and C as radii, draw two intersecting arcs. Connect point

3 with 1 and 2. Equilateral and isosceles triangles are drawn in the same way. The right triangle is drawn by using units of 6, 8, and 10 for the sides.

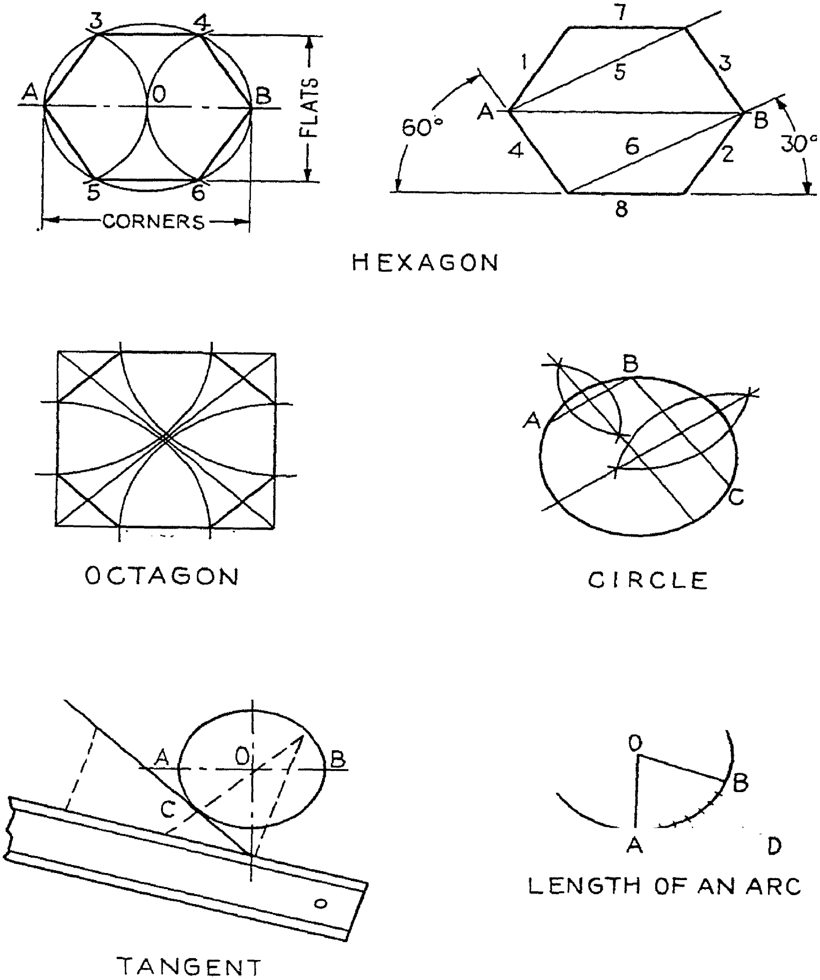


FIG. 29.—Graphic solutions, part 2.

The regular hexagon can be drawn in two ways (see Fig. 29). If the distance across corners, AB, is given, draw a circle with AB as the diameter. With A and B as centers and the same radius, draw arcs. Connect points A, 3, 4, B, 6, and 5. The second method is by the use of the 60°-30° triangle, drawing lines as numbered in the second part of Fig. 29.

To draw an octagon, first draw a square and the diagonals. With the corners as centers and half the diagonal as a radius, draw arcs. Where these arcs cut the side of the square, connect the points (Fig. 29).

A circle may be drawn through any three points that do not lie on a straight line, such as points A, B, and C (Fig. 29). Draw lines AB and BC. Bisect these lines in the manner already explained. These bisecting lines meet at O. With O as the center and OC as a radius, draw the circle.

A tangent to a circle at any point can be drawn (Fig. 29) by arranging a triangle and T-square in combination so that the hypotenuse of the triangle passes through the center O and point C. Hold the T-square firm, and invert the triangle so that the hypotenuse passes through point C.

While laying off on a straight line the approximate length of a circle arc, arc AB (Fig. 29), first draw the tangent AD. Set the dividers to a small space, starting at B, step along the arc to the point *nearest* A, and *without lifting the dividers* step off the same number of spaces on the tangent.

Figure 30 shows three ways to draw a tangent to two lines. Given the two lines AB, CD, and the radius R, draw two lines parallel to AB and CD at R distance out from the given lines. The intersection of these gives the center O, for the circle with R radius. Connect point O with perpendicular to AB and CD. Where they touch the circle is the point of tangency.

As stated earlier, the projection of a circle on a plane, when the circle is at some angle to the plane, is an ellipse, and an ellipse may be defined as a curve generated by a point, moving so that the sum of its distances from two fixed points is always constant. These two points are called *foci*.

If two diameters are drawn on a circle perpendicular to each other and the circle is rotated about one of these diameters, that diameter will remain constant in length, but the other one will become foreshortened, and the circle will become an ellipse. The diameter remaining constant is the *major axis*, and the foreshortened diameter is the *minor axis*. The length of the major and minor axes must be given.

The easiest way to make a large ellipse is the pin-and-string method (Fig. 30). Given the major and minor axes, locate the foci F_1 and F_2 by cutting the major axis at two points with an

arc, using point C as the center and one-half the major axis as the radius. Drive pins at F_1, F_2, and C, and tie a cord tightly around the three pins. Remove pin C. Place a marking point in the loop. Keeping the cord taut, move the marking point. This will describe an ellipse.

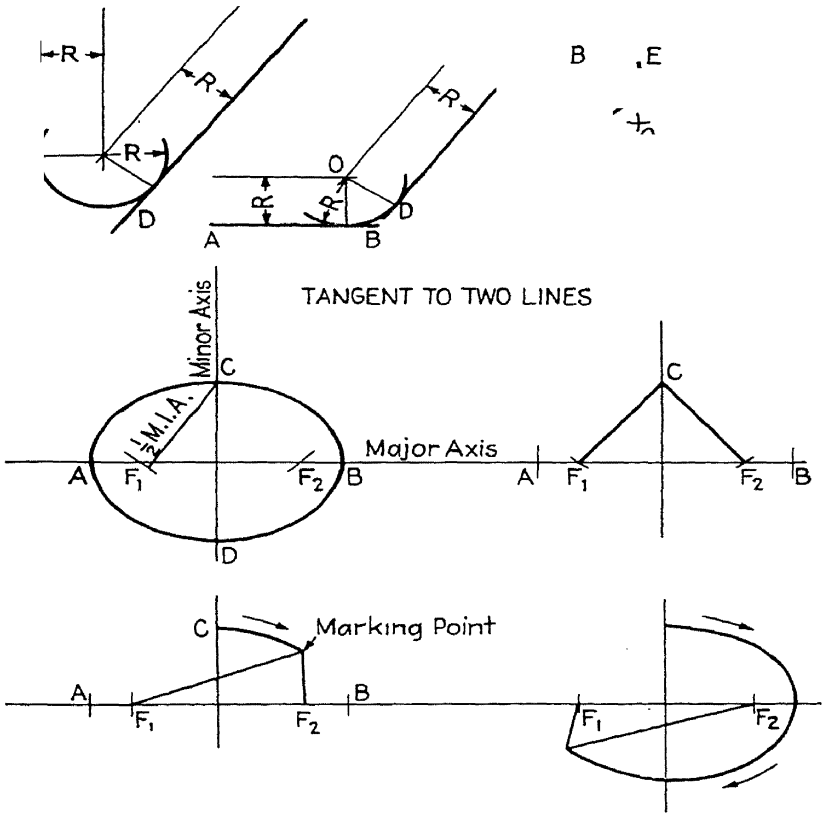


FIG. 30.—Graphic solutions: tangent to two lines; an ellipse by pin-and-string method.

The most accurate method for drawing an ellipse is by the two-circle method shown in Fig. 31. Given the major and minor axes crossing at O, using O as the center and the major and minor axes as the diameter, draw two circles. Divide arc ED in three equal parts EA, AB, and BD. Now divide arc BD into two equal parts, giving arcs BC and CD. Connect points A, B, and C with O. Where line AO cuts the circumference of the smaller circle is point F. Draw line 2 parallel to EE' and line

even number of sides (Fig. 34). The length of the stretch line is now the circumference of the circle. Divide it into the same

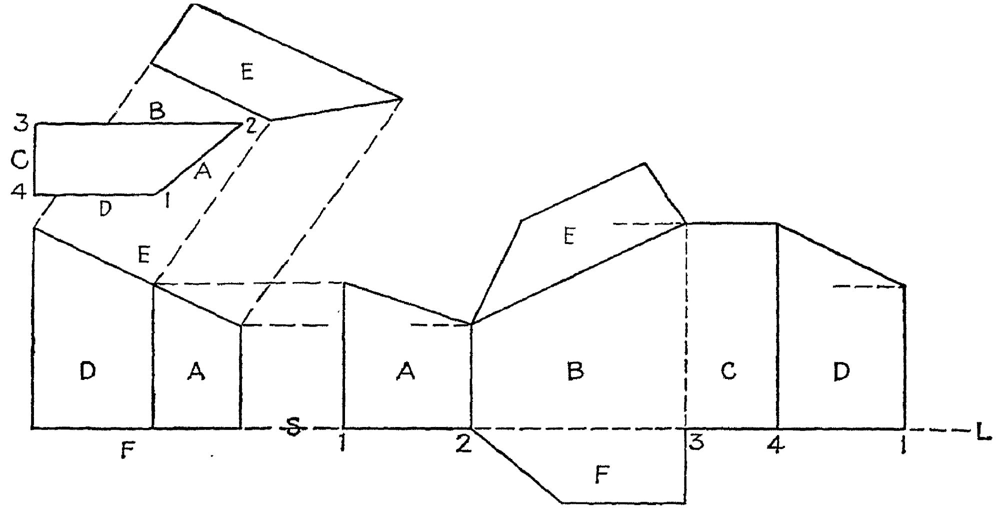


FIG. 33.—Pattern for a prism.

number of spaces as the circle. At each point, draw the imaginary vertical crease lines. Project the length of each imaginary edge across from the front view. The intersections of the projection

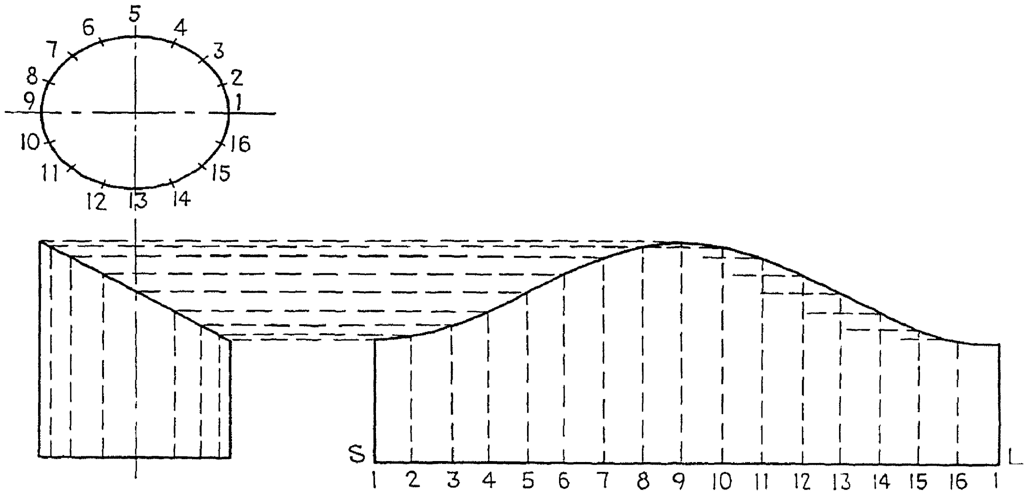


FIG. 34.—Pattern for a 90° elbow.

lines and the imaginary lines give a group of points. Draw a smooth curve through these points.

The pattern for a 90° elbow is made in exactly the same way, except that the angle cut on the cylinder is 45°. Since both halves are equal, only one need be developed.

The development of a four-piece elbow is illustrated in Fig. 35. To draw the elbow, first draw arcs having the desired inner and outer radii as shown in part *A*. Divide the outer quarter circle into six parts. To locate the joints, draw radial lines from points

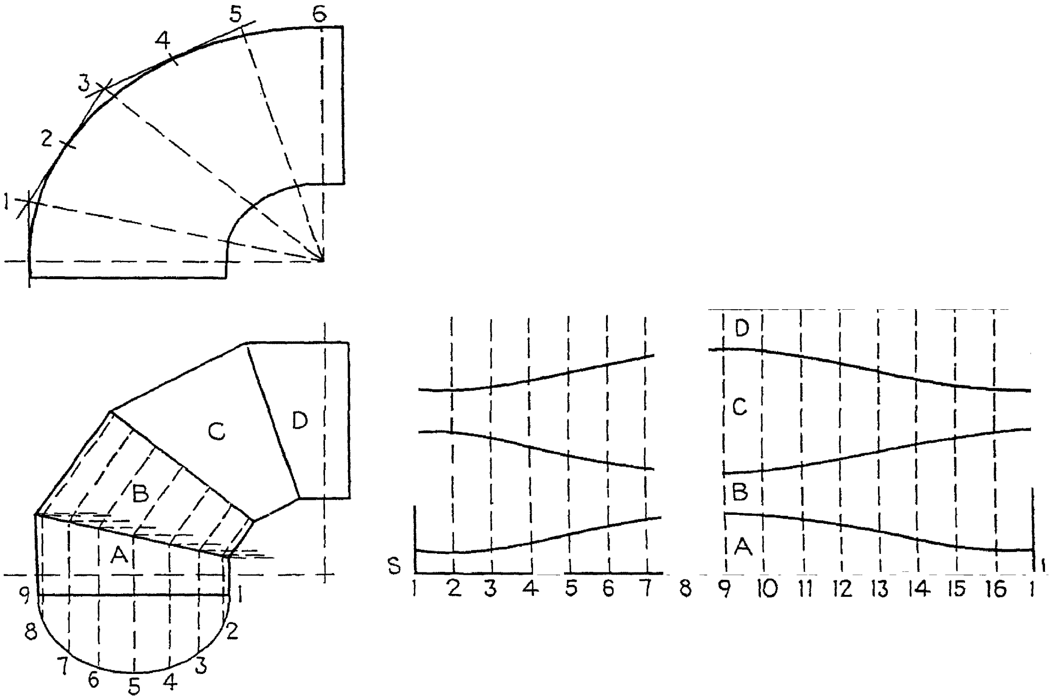


FIG. 35.—Pattern for a four-piece elbow.

1, 3, and 5. Draw tangents to the arcs at points 2 and 4. Repeat for the inner quarter circle. The figure is now ready for the projection. Draw the semicircle in part *B*. Divide it into equal parts; lay out the stretchout line; and complete the projection in the same manner as for the 90° angle in Fig. 34. Since sections *B*, *C*, and *D* all have the same angle as *A*, they have the same curve and can be drawn on the same rectangular sheet. When the layout is complete, it looks like part *C*, Fig. 35.

The stretchout lines for prisms and cylinders were all perpendicular to the lateral faces, the faces were all parallel to each other,

and the true lengths were easily obtained from the front view. However, in the case of pyramids, cones, or any similar object the stretchout line cannot be a straight line because the object does not roll out straight. Also, because the sides are not always parallel to the plane of projection, the true length is not shown.

To find the true length of a line, revolve that line until it is parallel to one of the planes of projection. Then project it to the parallel plane. This projection will give the true length of the line. Part *A*, Fig. 36, shows the top and front views of a pyramid. Since the edge *AO* is not parallel to any plane, the true

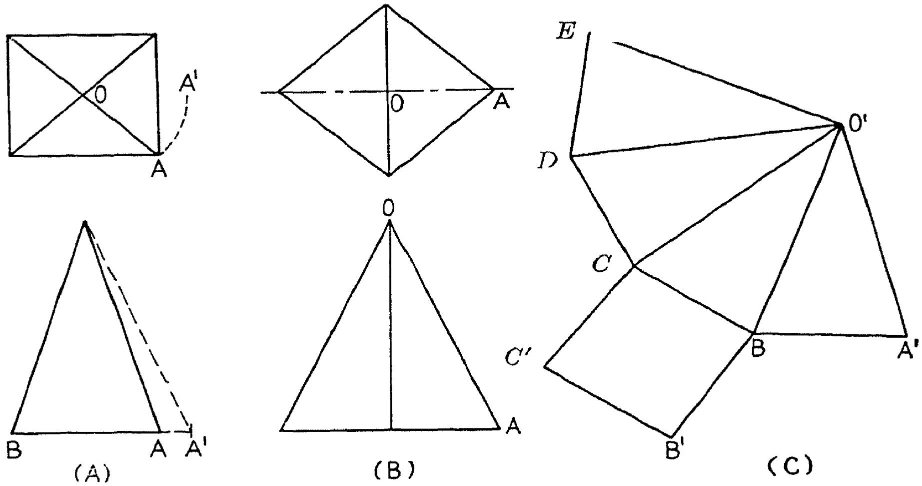


FIG. 36.—Pattern for a pyramid.

length is not shown; but, by rotating the pyramid until *AO* takes the position shown in part *B*, the true length is obtained. Therefore, the procedure for finding the true length of a line is as follows: In the top view with *OA* as radius and *O* as center, revolve *OA* until it is horizontal with the front view. Join *A′* and *O* in the front view. This line is the true length.

To lay out the pattern for the pyramid (part *C*, Fig. 36), use distance *OA′* as radius and *O′* as the center. Draw arc *A′E*. Divide arc *A′E* into four equal parts, each equal to distance *AB*. Draw lines *O′A′*, *O′B*, *O′C*, *O′D*, *O′E*, *A′B*, *BC*, *CD*, and *DE*. To base *BC* draw square *BB′C′C*.

In drawing the cylinder, it was considered to be a prism of many sides. Therefore, in laying out the pattern for a cone, consider that it is a many-sided pyramid. The length *OA* of the

cone in Fig. 37 is the true length. Therefore, with OA as a radius and point O' as the center, draw arc AB. The length of

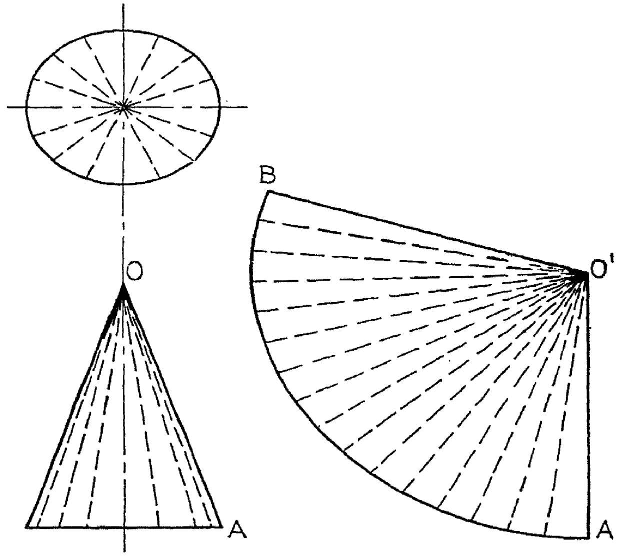


FIG. 37.—Pattern for a cone.

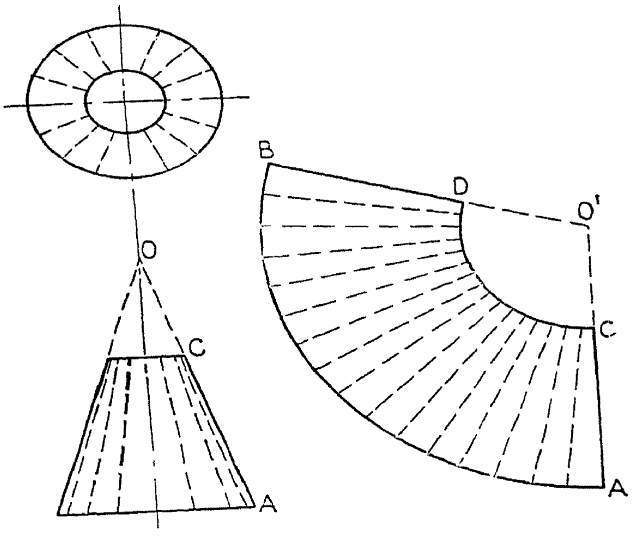


FIG. 38.—Pattern for a frustum of a cone.

the arc AB is equal to the circumference of the base of the cone. This distance can be obtained by dividing the base circle into little arcs of approximately $\frac{3}{16}$ in. and then laying off the same

number of little arcs on the arc AB. Connect $O'A$ and $O'B$. This gives the layout plan for the cone.

To lay out the frustum of a cone (Fig. 38), lay out arc AB the same as in Fig. 37. Draw arc CD, and remove part CDO'. The remaining portion is the pattern for the frustum of the cone.

A truncated cone is a cone like the one in Fig. 39. To lay out the pattern for this type of cone, lay out arc AB the same as in Fig. 37. Extend all imaginary lines to line OA. The lengths of these lines on OA now are the true lengths. Take distance

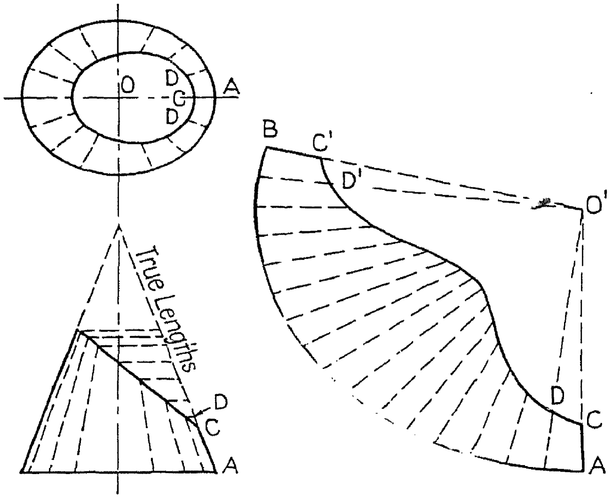


Fig. 39.—Pattern for a truncated cone.

OC and place on $O'A$, and so on for OD, etc. Since the rear half of the cone is the same as the front half, distance $O'C'$ is equal to $O'C$, etc. By drawing a smooth curve through points CD, etc., the pattern is obtained.

So far only the development of single objects has been studied. Now it is necessary to study surface intersection, for both the designer and the sheet-metal worker must be able to locate the line of intersection on surface intersection.

Given square block Y cut by triangular block X. In drawing the three orthographic views (Fig. 40), all lines are easy to draw except lines 1-2, 2-5, 5-3, and 3-4. As has been seen, lines intersect to give points. Therefore, number all points and project all points from one view to the other. The numbering of these points greatly aids in making the drawing.

The drawing of the intersection of two cylinders N and P is shown in Fig. 41. Divide the circle N into an even number of

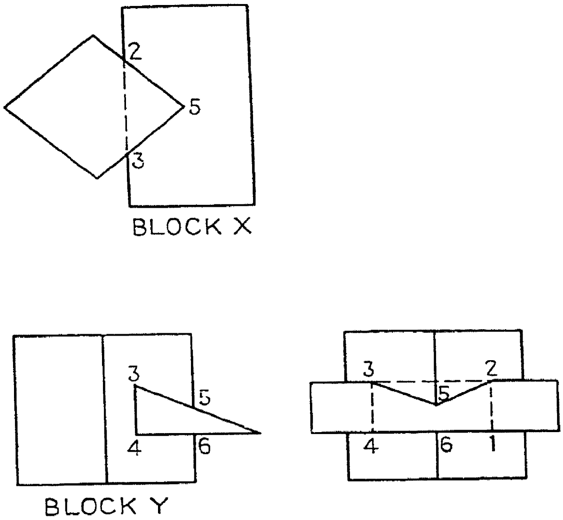


FIG. 40.—Two intersecting prisms.

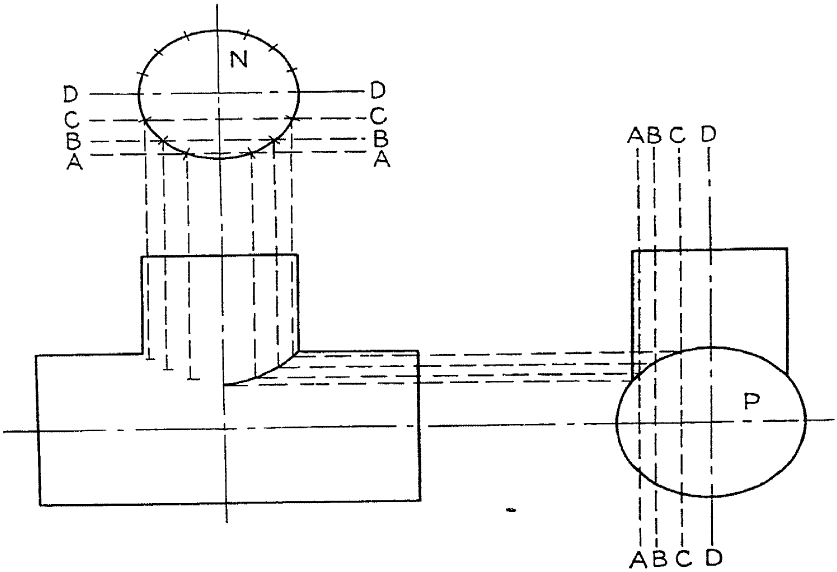


FIG. 41.—Two intersecting cylinders.

parts. Pass cutting planes AA, BB, CC, and DD through these points as shown. Project the cutting planes to the two other

views. The planes will cut the circle *P* in the end view. Extend the cut points horizontally until they intersect the vertical projection of the cutting planes in the front view. Draw a smooth curve through the points. The development of the cylinders can be made from these lengths.

The cutting-plane projection can also be used on prism intersection.

ISOMETRIC DRAWING

Isometric drawings, because they approach picture drawings, are rapidly replacing the orthographic form of drawing in some branches of the industry. Figure 42 is a good example of such drawings.

The isometric drawing shows three views in one—top, front, and right side. It is easier to explain this drawing as it is made. Given the three-view drawing of the block in part *A*, Fig. 43, draw vertical line *YY* shown in part *B*. At any point *O*, draw line *ZO* and *XO*, 30° from the horizontal as shown. These three lines are called the *isometric axes*.

Certain rules to be followed in isometric drawing are given below:

1. All vertical lines shown in the front and side views of an orthographic drawing are drawn vertical or parallel to *YY*.
2. All horizontal lines shown in the front view must be drawn parallel to *ZO*.
3. All horizontal lines shown in the end view must be drawn parallel to *XO*.
4. All lines parallel to *YY*, *ZO*, and *XO* show the true lengths of these lines.
5. All lines not parallel to *YY*, *ZO*, and *XO* do not show the true lengths of these lines.
6. Angles between lines on isometric drawings do not show their true size and cannot be measured in degrees.
7. Circles will appear as ellipses in isometric drawing, but instead of a true ellipse a four-centered approximation is usually made.

With the above in mind, return to part *B*, Fig. 43. On line *YY*, lay off distance 1-5. Then lay off, on *ZO*, distance 1-2, and parallel to *ZO*, at a distance 1-5 up, lay off 5-6. On line *OX*, lay off distance 1-4; and at a distance 1-5 up, parallel to *OX*, lay

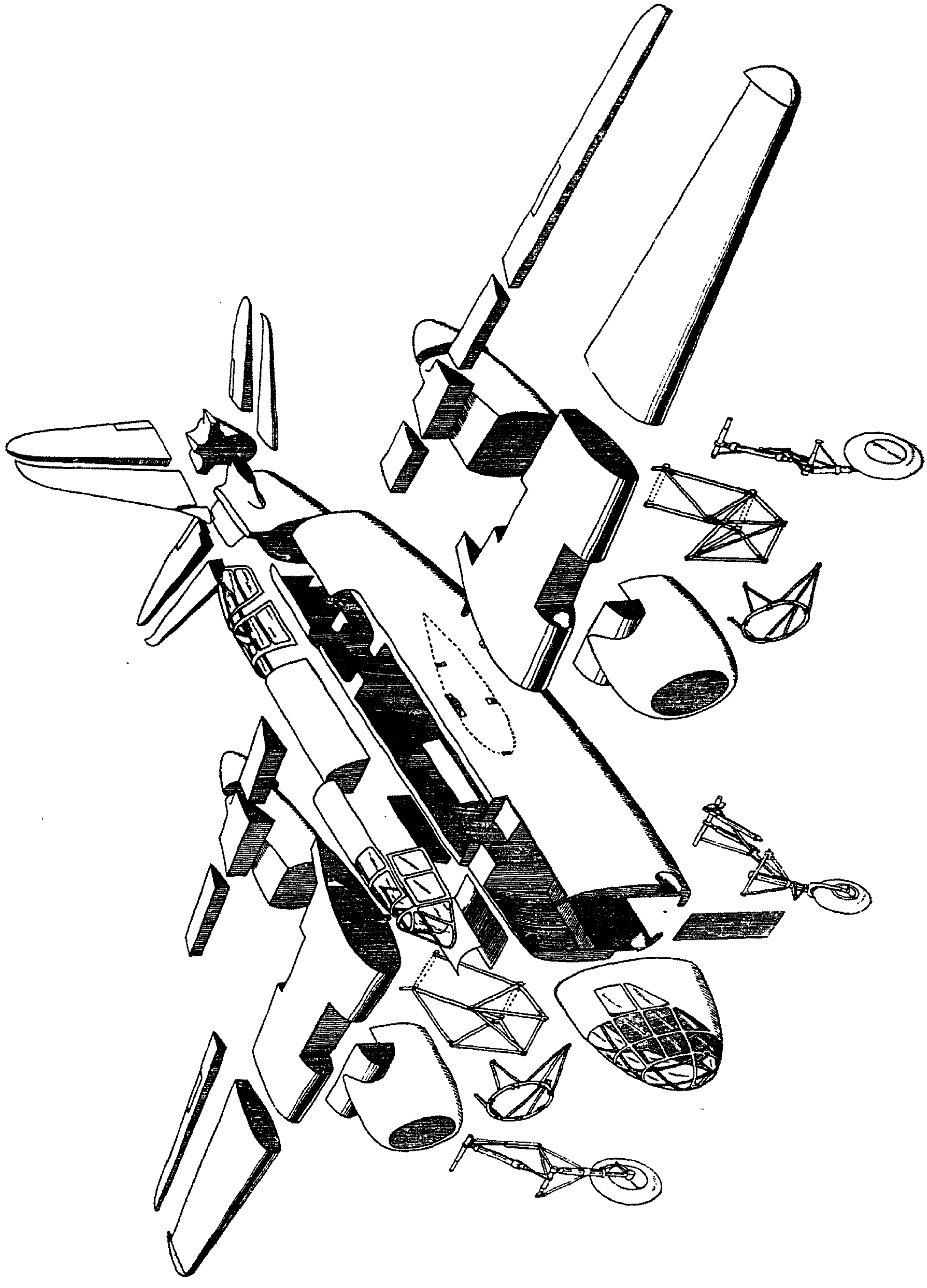


FIG. 42.—Typical production breakdown for a Douglas light bomber.

off 5-8. Now draw 2-6 and 4-8. Parallel to 5-6 and 5-8, draw 6-7 and 8-7. This completes the isometric drawing.

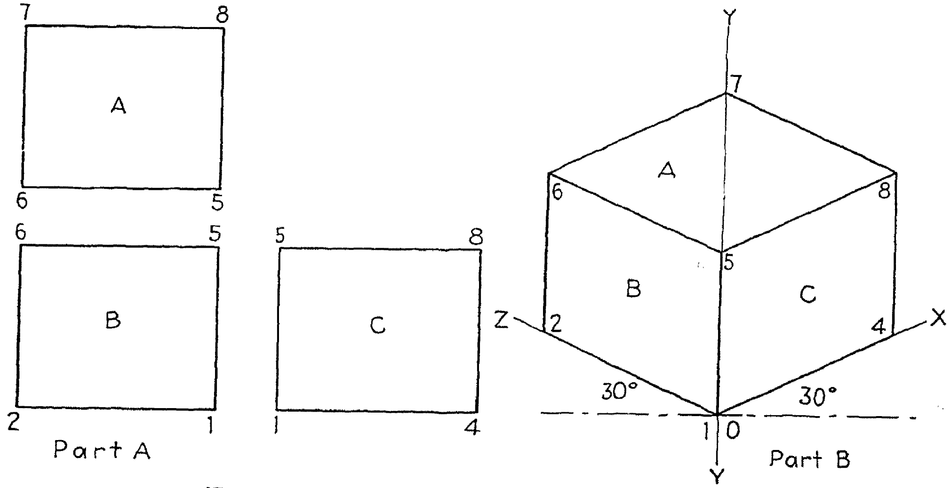


FIG. 43.—An isometric drawing of a cube.

It is necessary to be able to lay out circles on all three sides. This is shown in Fig. 44. From point 1, draw two lines, 1-6 and

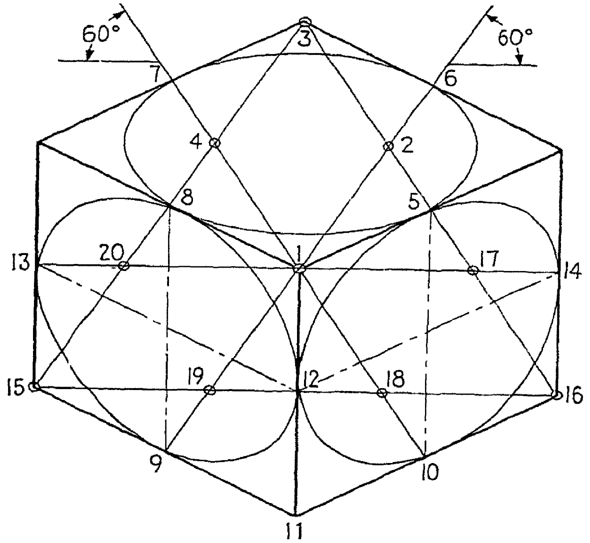


FIG. 44.—An isometric drawing of a circle-ellipse.

1-7, 60° to the horizontal. From point 3, likewise draw 3-8 and 3-5. The intersection of 1-7, 3-8 and 1-6, 3-5 gives points 4

and 2, respectively. With points 1 and 3 as centers, draw arcs 6-7 and 5-8. With points 2 and 4 as centers, draw arcs 5-6 and 7-8. This is a circle-ellipse on the top surface of an isometric drawing.

To draw the circle-ellipse on the front surface, bisect line 1-11, giving point 12 (Fig. 44). Draw line 12-13 parallel to base line 11-15. Bisect line 11-15, and draw 8-9 parallel to 1-11. Draw lines 8-15, 1-13, 1-9, and 12-15. These lines intersect at points 19 and 20. With points 1 and 15 as centers, draw arcs 9-13 and 8-12. With points 19 and 20 as centers, draw arcs 9-12 and 8-13. The circle-ellipse for the end face is drawn in the same manner.

CHAPTER II

SHOP MATHEMATICS

FRACTIONS

General

Numbers are called whole numbers, fractions, or mixed numbers. Whole numbers are such numbers as 1, 12, 20, etc. Fractions are some fraction of a whole number, as $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{3}$, etc. Mixed numbers are a combination of both whole numbers and fractions, as $1\frac{1}{2}$, $2\frac{3}{4}$, etc.

The fraction is made up of two parts, or terms. The number above the line is called the *numerator*, and the number below the line is called the *denominator*. The denominator tells how many parts the object is to be divided into, and the numerator tells how many parts have been taken.

Example: "Jack ate one-fourth ($\frac{1}{4}$) of the cake." This tells that the cake was cut into four equal parts. "Jack put the remaining three-fourths ($\frac{3}{4}$) of the cake in the cakebox." This tells that three (3) of the four parts were left.

A fraction whose value is less than unity or whose numerator is less than the denominator, as $\frac{3}{4}$, is called a *proper fraction*.

A fraction whose value is equal to or greater than unity, or whose numerator is equal to or greater than the denominator is called an *improper fraction*, as $\frac{4}{4}$ or $\frac{5}{4}$.

To Reduce Whole or Mixed Numbers to Improper Fractions

Reduce 3 to fifths. Since every unit must be divided into 5 equal parts, multiply 3 by $\frac{5}{5}$, or

$$3 \times \frac{5}{5} = \frac{15}{5} \qquad \textit{Ans.}$$

Reduce the following to improper fractions:

4 to eighths $\qquad 4 \times \frac{8}{8} = \frac{32}{8}$

2 to halves $\qquad 2 \times \frac{2}{2} = \frac{4}{2}$

6 to fifths $\qquad 6 \times \frac{5}{5} = \frac{30}{5}$

Reduce $8\frac{3}{5}$ to fifths. Since there are 8 whole units to be divided into 5 equal parts, plus 3 fifths, multiply 8 by $\frac{5}{5}$ and add 3 fifths, or

$$8 \times \frac{5}{5} + \frac{3}{5} = \frac{43}{5}$$

Reduce the following to improper fractions:

$4\frac{1}{2}$ to halves $\qquad 4 \times \frac{2}{2} + \frac{1}{2} = \frac{8}{2} + \frac{1}{2} = \frac{9}{2}$

$6\frac{1}{8}$ to eighths $\qquad 6 \times \frac{8}{8} + \frac{1}{8} = \frac{48}{8} + \frac{1}{8} = \frac{49}{8}$

$8\frac{3}{4}$ to fourths $\qquad 8 \times \frac{4}{4} + \frac{3}{4} = \frac{32}{4} + \frac{3}{4} = \frac{35}{4}$

Problems: Reduce the following to improper fractions:

1. 5 to halves; 7 to halves
2. 6 to fourths; 8 to fourths
3. 21 to eighths; 14 to eighths
4. 42 to sixteenths; 8 to sixteenths
5. 7 to fourths; 9 to fourths
6. $3\frac{1}{2}$ to halves; $5\frac{1}{2}$ to halves
7. $12\frac{2}{3}$ to thirty-seconds; $4\frac{2}{3}$ to thirty-seconds
8. $15\frac{1}{4}$ to fourths; $9\frac{1}{4}$ to fourths
9. $2\frac{3}{10}$ to tenths; $3\frac{7}{10}$ to tenths
10. $5\frac{2}{8}$ to eighths; $7\frac{3}{8}$ to eighths

To Reduce Improper Fractions to Whole or Mixed Numbers

Reduce $\frac{64}{8}$ to a whole number. Divide 64 by 8, and get $64 \div 8 = 8$.

Reduce the following to whole numbers:

$$\frac{24}{3} = 24 \div 3 = 8; \qquad \frac{36}{4} = 36 \div 4 = 9; \qquad \frac{27}{9} = 27 \div 9 = 3$$

Reduce $\frac{13}{6}$ to mixed numbers. Divide 13 by 6, and get $13 \div 6 = 2\frac{1}{6}$.

Reduce the following to mixed numbers:

$$\frac{25}{4} = 25 \div 4 = 6\frac{1}{4}; \quad \frac{29}{7} = 29 \div 7 = 4\frac{1}{7}; \quad \frac{10}{3} = 10 \div 3 = 3\frac{1}{3}$$

Problems: Reduce to whole or mixed numbers:

1. $\frac{24}{8}$; $\frac{36}{6}$ $\frac{27}{3}$	**2.** $\frac{21}{7}$; $\frac{14}{2}$; $\frac{9}{3}$
3. $\frac{10}{5}$; $\frac{16}{4}$; $\frac{15}{3}$	**4.** $\frac{20}{4}$; $\frac{14}{8}$; $\frac{8}{2}$
5. $\frac{16}{8}$; $\frac{32}{16}$; $\frac{42}{32}$	**6.** $\frac{46}{8}$; $\frac{55}{16}$; $\frac{25}{2}$
7. $\frac{19}{8}$; $\frac{65}{8}$; $\frac{43}{4}$	**8.** $\frac{32}{8}$; $\frac{64}{4}$; $\frac{38}{32}$
9. $\frac{29}{3}$; $\frac{53}{5}$; $\frac{67}{16}$	**0.** $\frac{225}{16}$; $\frac{116}{12}$; $\frac{130}{64}$

To Reduce a Fraction to Lowest Terms

Two numbers are *prime to each other* when they have no common divisor, or factor. For example, 3 and 4 are prime to each other because no number will divide both of them without a remainder. 6 and 8 can both be divided by 2 without a remainder; therefore, they are not prime to each other.

To reduce a fraction to lowest terms, divide both numerator and denominator by the largest common factor.

$$\frac{12}{16} = \frac{12 \div 4}{16 \div 4} = \frac{3}{4}$$

12 and 16 are both divisible by 2 and 4 without a remainder. Since 4 is the larger, we divide both by 4. The answer, $\frac{3}{4}$, is equal in value to the original fraction, $\frac{12}{16}$.

Reduce the following to lowest terms:

$$\frac{12}{14} \quad \frac{12 \div 2}{14 \div 2} \qquad \frac{15}{40} = \frac{15 \div 5}{40 \div 5} = \frac{3}{8}; \qquad \frac{12}{16} = \frac{12 \div 4}{16 \div 4} = \frac{3}{4}$$

llowing to lowest terms:

1. $\frac{24}{48}$; $\frac{24}{32}$; $\frac{25}{35}$	**2.** $\frac{9}{12}$; $\frac{8}{24}$; $\frac{2}{4}$
3. $\frac{3}{12}$; $\frac{5}{15}$; $\frac{2}{32}$	**4.** $\frac{6}{18}$; $\frac{12}{32}$; $\frac{7}{14}$
5. $\frac{42}{96}$; $\frac{18}{36}$; $\frac{16}{64}$	**6.** $\frac{12}{96}$; $\frac{15}{45}$; $\frac{10}{35}$
7. $\frac{13}{26}$; $\frac{24}{144}$; $\frac{16}{96}$	**8.** $\frac{11}{44}$; $\frac{14}{28}$; $\frac{17}{34}$
9. $\frac{21}{49}$; $\frac{27}{81}$; $\frac{24}{64}$	**10.** $\frac{49}{84}$; $\frac{120}{160}$; $\frac{11}{22}$

To Increase the Denominator of a Fraction

To change a fraction with a given denominator to one with a higher denominator, divide the new denominator by the old denominator, and multiply both the numerator and denominator by the answer.

To change $\frac{1}{2}$ to eighths $\quad 8 \div 2 = 4; \quad \frac{1}{2} \times \frac{4}{4} = \frac{4}{8}$

If the old denominator will not divide into the new denominator an even number of times, it will be impossible to make the change.

To change

$\frac{3}{4}$ to sixteenths $\quad \frac{3}{4} \times \frac{4}{4} = \frac{12}{16}$

$\frac{2}{5}$ to twentieths $\quad \frac{2}{5} \times \frac{4}{4} = \frac{8}{20}$

$\frac{3}{7}$ to twenty-firsts $\quad \frac{3}{7} \times \frac{3}{3} = \frac{9}{21}$

Problems: Change:

1. $\frac{1}{2}$ to eighths; $\frac{1}{2}$ to fourths; $\frac{1}{2}$ to tenths
2. $\frac{3}{8}$ to sixteenths; $\frac{3}{8}$ to thirty-seconds; $\frac{3}{8}$ to sixty-fourths
3. $\frac{1}{4}$ to sixteenths; $\frac{1}{4}$ to sixty-fourths; $\frac{1}{4}$ to thirty-seconds
4. $\frac{1}{5}$ to fifteenths; $\frac{1}{5}$ to twenty-fifths; $\frac{1}{5}$ to thirtieths
5. $\frac{1}{3}$ to ninths; $\frac{2}{3}$ to twelfths; $\frac{2}{3}$ to twenty-sevenths
6. $\frac{5}{6}$ to eighteenths; $\frac{5}{6}$ to twenty-fourths; $\frac{5}{6}$ to thirtieths
7. $\frac{7}{8}$ to thirty-seconds; $\frac{7}{8}$ to sixty-fourths; $\frac{7}{8}$ to sixteenths
8. $\frac{3}{4}$ to eighths; $\frac{3}{4}$ to sixteenths; $\frac{3}{4}$ to sixty-fourths

To Find the Least Common Denominator for Two or More Fractions

To obtain the common denominator for two or more fractions, select a number that all denominators will *divide into evenly*, and change all denominators to that value. The least common denominator is the smallest such number possible.

Obtain the least common denominator for $\frac{1}{4}$, $\frac{1}{5}$, $\frac{3}{10}$. 4, 5, and 10 will divide evenly into both 40 and 20. Since 20 is the smallest number that all three will go into evenly, that number will be used.

$$\frac{1}{4} = \frac{1}{4} \times \frac{5}{5} = \frac{5}{20}; \qquad \frac{1}{5} = \frac{1}{5} \times \frac{4}{4} = \frac{4}{20}; \qquad \frac{3}{10} = \frac{3}{10} \times \frac{2}{2} = \frac{6}{20}$$

Problems: Obtain the least common denominator:

1. $\frac{1}{3}; \frac{11}{18}; \frac{5}{6}$
2. $\frac{2}{5}; \frac{1}{4}; \frac{5}{8}$
3. $\frac{2}{7}; \frac{2}{3}; \frac{5}{6}$
4. $\frac{1}{6}; \frac{2}{3}; \frac{5}{9}$
5. $\frac{4}{9}; \frac{3}{7}; \frac{2}{5}$
6. $\frac{12}{15}; \frac{3}{5}; \frac{1}{6}$
7. $\frac{3}{5}; \frac{3}{4}; \frac{1}{7}$
8. $\frac{10}{13}; \frac{1}{2}; \frac{5}{26}$

Addition of Fractions

To add fractions, obtain the least common denominator for all the fractions, add the new numerators, and put the sum of the new numerator over the least common denominator.

Add $\frac{1}{4} + \frac{2}{3} + \frac{5}{6}$. The least common denominator is 12.

$$\frac{1}{4} = \frac{1}{4} \times \frac{3}{3} = \frac{3}{12}$$
$$\frac{2}{3} = \frac{2}{3} \times \frac{4}{4} = \frac{8}{12}$$
$$\frac{5}{6} = \frac{5}{6} \times \frac{2}{2} = \frac{10}{12}$$

Now add all numerators: $3 + 8 + 10 = 21$. Place the sum over the new denominator: $\frac{21}{12}$. This is the sum of the fractions given. However, whenever possible, the answer must be reduced to a mixed number and/or to its lowest terms:

$$\frac{21}{12} = 1\frac{9}{12} = 1\frac{3}{4}.$$

Problems: Add the following:

1. $\frac{3}{4} + \frac{1}{2} + \frac{5}{8}$
2. $\frac{5}{8} + \frac{3}{4} + \frac{7}{32}$
3. $\frac{7}{8} + \frac{3}{4} + \frac{5}{16}$
4. $\frac{1}{8} + \frac{5}{12} + \frac{11}{18}$
5. $\frac{3}{7} + \frac{5}{14} + \frac{7}{18}$
6. $\frac{1}{2} + \frac{3}{4} + \frac{5}{8}$
7. $\frac{9}{16} + \frac{7}{8} + \frac{15}{32}$
8. $\frac{2}{3} + \frac{3}{4} + \frac{5}{7} + \frac{7}{12}$
9. $\frac{7}{8} + \frac{3}{4} + \frac{5}{16} + \frac{15}{32}$
10. $\frac{15}{16} + \frac{8}{2} + \frac{3}{4}$

Addition of Mixed Numbers

To add mixed numbers, change the mixed numbers to improper fractions. Convert the improper fractions to the least common denominator, and add.

To add $2\frac{1}{2} + 3\frac{1}{4} + 4\frac{5}{6}$, change to improper fractions.

$$2\frac{1}{2} = 2 \times \frac{2}{2} + \frac{1}{2} = \frac{5}{2}; \qquad 3\frac{1}{4} = 3 \times \frac{4}{4} + \frac{1}{4} = \frac{13}{4};$$

$$4\frac{5}{6} = 4 \times \frac{6}{6} + \frac{5}{6} = \frac{29}{6}$$

Then obtain the least common denominator:

$$\frac{5}{2} = \frac{5}{2} \times \frac{6}{6} = \frac{30}{12}; \qquad \frac{13}{4} = \frac{13}{4} \times \frac{3}{3} = \frac{39}{12}; \qquad \frac{29}{6} = \frac{29}{6} \times \frac{2}{2} = \frac{58}{12}$$

Then add.

$$\frac{30}{12} + \frac{39}{12} + \frac{58}{12} = \frac{127}{12} = 10\frac{7}{12}$$

As above, the answer should be reduced to mixed numbers or lowest terms.

Problems: Add the following mixed numbers:

1. $2\frac{1}{8} + 4\frac{1}{4} + 6\frac{1}{32}$

2. $7\frac{1}{2} + 9\frac{1}{16} + 3\frac{1}{32}$

3. $10\frac{3}{8} + 6\frac{5}{8} + 1\frac{1}{4}$

4. $12\frac{1}{4} + \frac{1}{16} + 1\frac{1}{8}$

5. $1\frac{2}{3} + 6\frac{1}{2} + 9\frac{1}{5}$

6. $6\frac{3}{5} + 2\frac{5}{8} + 4\frac{3}{10}$

7. $8\frac{1}{2} + 6\frac{1}{8} + 9\frac{1}{4}$

8. $12\frac{1}{2} + 1\frac{5}{8} + 2\frac{1}{16}$

9. $7\frac{1}{4} + 3\frac{5}{8} + 4\frac{1}{16}$

10. $10\frac{1}{3} + 11\frac{1}{4} + 12\frac{1}{8}$

Subtraction of Fractions

To subtract fractions, *obtain the least common denominator, and subtract the numerators,* placing the sum over the common denominator.

To subtract $\frac{2}{3} - \frac{1}{4}$, obtain the least common denominator.

$$\frac{1}{4} = \frac{1}{4} \times \frac{3}{3} = \frac{3}{12}$$

$$\frac{2}{3} = \frac{2}{3} \times \frac{4}{4} = \frac{8}{12}$$

Subtract the new numerators: $8 - 3 = 5$. Place the answer over the least common denominator, and get $\frac{5}{12}$.

If necessary, this answer must also be reduced to smallest terms.

Problems: Subtract the following fractions:

1. $\frac{1}{2} + \frac{1}{8} - \frac{1}{4}$
2. $\frac{1}{3} - \frac{1}{4}$
3. $\frac{7}{8} - \frac{1}{8} + \frac{1}{32}$
4. $\frac{3}{64} + \frac{5}{8} - \frac{6}{16}$
5. $\frac{4}{9} + \frac{2}{3} - \frac{5}{6}$
6. $\frac{9}{16} - \frac{3}{8}$
7. $\frac{24}{48} + \frac{1}{4} - \frac{2}{3}$
8. $\frac{15}{32} + \frac{5}{8} - \frac{3}{4}$
9. $\frac{15}{16} - \frac{4}{8}$
10. $\frac{21}{42} - \frac{5}{6} + \frac{1}{2}$

Subtraction of Mixed Numbers

To subtract mixed numbers, change the numbers to improper fractions, obtain the least common denominator, subtract the new numerators, and place the answer over the least common denominator.

$2\frac{3}{4} - 1\frac{1}{3}$. To subtract $1\frac{1}{3}$ from $2\frac{3}{4}$, change the mixed numbers to improper fractions:

$$1\frac{1}{3} = 1 \times \frac{3}{3} + \frac{1}{3} = \frac{4}{3}; \qquad 2\frac{3}{4} = 2 \times \frac{4}{4} + \frac{3}{4} = \frac{11}{4}$$

Obtain the least common denominator.

$$\frac{4}{3} = \frac{4}{3} \times \frac{4}{4} = \frac{16}{12}$$
$$\frac{11}{4} = \frac{11}{4} \times \frac{3}{3} = \frac{33}{12}$$

Subtract the new numerators: $33 - 16 = 17$. Place the answer over the least common denominator, and get $\frac{17}{12}$.

If possible, reduce to mixed numbers and lowest terms, $\frac{17}{12} = 1\frac{5}{12}$.

Problems: Subtract the following mixed numbers:

1. $2\frac{1}{8} + 1\frac{1}{4} - 1\frac{1}{2}$
2. $6\frac{3}{4} - 6\frac{1}{8} + 1\frac{1}{16}$
3. $15\frac{7}{8} - 5\frac{1}{2}$
4. $14\frac{5}{7} - 7\frac{2}{3}$
5. $16\frac{1}{2} + 1\frac{5}{8} - 4\frac{7}{16}$
6. $\frac{9}{15} - 1\frac{1}{7} + \frac{1}{2}$
7. $1\frac{13}{32} - \frac{15}{16}$
8. $10\frac{1}{3} + 5\frac{2}{5} - 6\frac{5}{6}$
9. $5\frac{2}{3} + 1\frac{3}{4} - 3\frac{11}{12}$
10. $1\frac{15}{16} - \frac{7}{8} - \frac{1}{4}$

Multiplication of Fractions

1. To multiply one fraction by another, multiply the numerators, and place the results over the product of the denominators.

To multiply

$$\frac{3}{4} \times \frac{5}{6} \qquad \frac{3 \times 5}{4 \times 6} = \frac{15}{24} = \frac{5}{8}$$

Reduce the results to whole or lowest terms as shown above.

To multiply

$$\frac{3}{4} \times \frac{7}{8} \qquad \frac{3 \times 7}{4 \times 8} = \frac{21}{32}$$

$$\frac{7}{9} \times \frac{3}{5} \qquad \frac{7 \times 3}{9 \times 5} = \frac{21}{45} = \frac{7}{15}$$

$$\frac{15}{8} \times \frac{2}{3} \qquad \frac{15 \times 2}{8 \times 3} = \frac{30}{24} = \frac{15}{12} = \frac{5}{4} \qquad 1\frac{1}{4}$$

ly the following:

1. $\frac{3}{8} \times \frac{1}{4}$
2. $\frac{5}{8} \times \frac{3}{16}$
3. $\frac{5}{8} \times \frac{24}{32}$
4. $\frac{16}{64} \times \frac{3}{4}$
5. $\frac{14}{9} \times \frac{5}{2}$
6. $\frac{1}{2} \times \frac{9}{16}$
7. $\frac{3}{5} \times \frac{1}{4}$
8. $\frac{2}{3} \times \frac{5}{6}$
9. $\frac{3}{4} \times \frac{1}{16}$
10. $\frac{7}{8} \times \frac{2}{3}$

2. To multiply a fraction by a whole number, multiply the numerator by the whole number and place the results over the denominator.

To multiply

$$\frac{\ }{3} \times 5 \qquad \frac{2 \times 5}{3} = \frac{10}{3} = 3\frac{1}{3}$$

The results should be reduced to mixed numbers and lowest terms as given above.

To multiply

$$\frac{4}{5} \times 6 \qquad \frac{4 \times 6}{5} = \frac{24}{5} = 4\frac{4}{5}$$

$$\frac{5}{8} \times 4 \qquad \frac{5 \times 4}{8} = \frac{20}{8} = 2\frac{4}{8} = 2\frac{1}{2}$$

$3 \times 2 \qquad \frac{3 \times 2}{4} = \frac{6}{4} = 1\frac{2}{4} = 1\frac{1}{2}$

Problems: Multiply the following:

1. $\frac{2}{3} \times 7$
2. $14 \times \frac{5}{8}$
3. $\frac{5}{\text{[illegible]}} \times 9$
4. $\frac{2}{7} \times 20$
5. $\frac{1}{2} \times 5$
6. $4 \times \frac{1}{16}$
7. $3 \times \frac{5}{8}$
8. $2 \times \frac{7}{8} \times$
9. $\frac{3}{4} \times 6$
10. $\frac{5}{7} \times 8$

3. To multiply fractions by mixed numbers, reduce the mixed numbers to improper fractions and multiply as in part 1.

To multiply

$$2\frac{1}{2} \times \frac{2}{3} \qquad \left(\frac{2 \times 2}{2} + \frac{1}{2}\right) \times \frac{2}{3} = \frac{5}{2} \times \frac{2}{3} = \frac{10}{6} = 1\frac{2}{3}$$

The results again should be reduced to mixed numbers and lowest terms as shown above.

To multiply

$$2\frac{1}{5} \times \frac{1}{2} \qquad \left(\frac{2 \times 5}{5} + \frac{1}{5}\right) \times \frac{1}{2} = \frac{11}{5} \times \frac{1}{2} = \frac{11}{10} = 1\frac{1}{10}$$

$$3\frac{1}{3} \times 3 \qquad \left(\frac{3 \times 3}{3} + \frac{1}{3}\right) \times 3 = \frac{10}{3} \times 3 = \frac{30}{3} = 10$$

$$4\frac{1}{2} \times 2\frac{1}{3} \qquad \left(\frac{4 \times 2}{2} + \frac{1}{2}\right) \times \left(\frac{2 \times 3}{3} + \frac{1}{3}\right) = \frac{9}{2} \times \frac{7}{3} = \frac{63}{6}$$

$$= 10\frac{3}{6} = 10\frac{1}{2}$$

Problems: Multiply the following:

1. $3\frac{2}{7} \times 8\frac{3}{4}$
2. $5\frac{5}{8} \times 2\frac{1}{2}$
3. $2\frac{1}{8} \times 4\frac{1}{2}$
4. $10\frac{1}{2} \times 12\frac{7}{8}$
5. $7\frac{1}{2} \times 3\frac{1}{4} \times 2\frac{1}{8}$
6. $5\frac{1}{4} \times 4$
7. $3\frac{2}{8} \times 7$
8. $2\frac{7}{8} \times 2$
9. $3\frac{1}{4} \times 4\frac{1}{16}$
10. $4\frac{1}{2} \times 6\frac{3}{8}$

4. To Multiply Fractions by Cancellation.—Whenever a number will divide evenly into one term of the numerators and denominators of two different fractions, these terms can be reduced by cancellation as shown below:

$$\frac{1}{4} \times \frac{2}{5} \times \frac{5}{6}$$

2 will divide evenly into 2 in the numerator and 4 in the denominator. Therefore, cross out 2 and place 1 above it; cross out 4 in the denominator and place 2 below it. 5 will also divide into 5 in the numerator and in the denominator.

$$\frac{1}{4} \times \frac{2}{5} \times \frac{5}{6} = \frac{1}{\underset{2}{\cancel{4}}} \times \frac{\overset{1}{\cancel{2}}}{5} \times \frac{5}{6} = \frac{1}{2} \times \frac{1}{\underset{1}{\cancel{5}}} \times \frac{\overset{1}{\cancel{5}}}{6} = \frac{1}{2} \times \frac{1}{1} \times \frac{1}{6} = \frac{1}{12}$$

Again, if possible, the answer should be reduced to mixed numbers:

$$\frac{4}{5} \times \frac{3}{4} \times \frac{7}{3} = \frac{\overset{1}{\cancel{4}}}{5} \times \frac{\overset{1}{\cancel{3}}}{\underset{1}{\cancel{4}}} \times \frac{7}{\underset{1}{\cancel{3}}} = \frac{7}{5} = 1\,\frac{2}{5}$$

$$\frac{2}{3} \times \frac{3}{5} \times \frac{9}{7} = \frac{2}{\cancel{3}} \times \frac{\cancel{3}}{5} \times \frac{9}{7} = \frac{18}{35}$$

$$\frac{1}{3} \times \frac{3}{4} \times \frac{2}{5} = \frac{1}{\cancel{3}} \times \frac{\cancel{3}}{\cancel{4}} \times \frac{\cancel{2}}{5} = \frac{1}{10}$$

Problems: Multiply by cancellation:

1. $\frac{14}{16} \times \frac{18}{28}$
2. $\frac{15}{28} \times \frac{14}{24}$
3. $\frac{7}{12} \times \frac{33}{56}$
4. $\frac{5}{8} \times \frac{24}{40}$
5. $\frac{2}{3} \times \frac{9}{16}$
6. $\frac{14}{15} \times \frac{5}{8} \times \frac{3}{4}$
7. $\frac{12}{14} \times \frac{9}{15} \times \frac{2}{3}$
8. $\frac{7}{8} \times \frac{24}{28} \times \frac{2}{5}$
9. $\frac{3}{4} \times \frac{2}{5} \times \frac{7}{9}$
10. $\frac{4}{5} \times \frac{7}{8} \times \frac{2}{3}$

Division of Fractions

To divide one fraction by another, invert the divisor and multiply. "Divide $\frac{5}{7}$ by $\frac{3}{4}$" may be written

$$\frac{5}{7} \div \frac{3}{4} \qquad \text{or} \qquad \frac{\frac{5}{7}}{\frac{3}{4}} = \frac{5}{7} \times \frac{4}{3} = \frac{20}{21}$$

After the divisor has been inverted for multiplication, cancellation may be used; also, the answer may be reduced to whole numbers.

$$\frac{\frac{3}{4}}{5} = \frac{3}{\cancel{4}} \times \frac{\overset{2}{\cancel{8}}}{5} = \frac{6}{5} = 1\frac{1}{5}$$

$$\frac{3}{5} \div 3 = \frac{\frac{3}{5}}{\frac{3}{1}} = \frac{\cancel{3}}{5} \times \frac{1}{\cancel{3}} = \frac{1}{5}$$

Problems: Divide the following:

1. $\frac{2}{3} \div \frac{5}{8}$
2. $\frac{1}{4}$ by $\frac{3}{8}$
3. $\frac{10}{15}$ by $\frac{7}{12}$
4. $\dfrac{\frac{25}{32}}{\frac{5}{8}}$
5. $\frac{11}{32} \div \frac{22}{48}$
6. $\dfrac{\frac{18}{25}}{3}$
7. $\frac{12}{8} \div 4$
8. $\dfrac{\frac{7}{8}}{5}$
9. $\frac{9}{16} \div \frac{3}{8}$
10. $\dfrac{\frac{11}{12}}{5}$

Combined Problems Involving Multiplication and Division

Whenever problems involving both multiplication and division are encountered, each process should be completed as described in the preceding paragraphs.

Solve the following:

(1) $\frac{1}{4} \times \frac{5}{8} \div \frac{5}{12}$ can be written

$$\frac{\frac{1}{4} \times \frac{5}{8}}{\frac{5}{12}} = \frac{1}{\cancel{4}} \times \frac{\cancel{5}}{8} \times \frac{\overset{3}{\cancel{12}}}{\cancel{5}} = \frac{3}{8}$$

(2) $$\frac{2}{5} \times \frac{1}{3} \div \frac{4}{3} = \frac{\frac{2}{5} \times \frac{1}{3}}{4} = \frac{\cancel{2}}{5} \times \frac{1}{\cancel{3}} \times \frac{\cancel{3}}{\cancel{4}} = \frac{1}{10}$$

$$\frac{15}{16} \times \frac{8}{10} \div \frac{15}{18} = \frac{\frac{15}{16} \times \frac{8}{10}}{\frac{15}{18}} = \frac{\cancel{15}}{\cancel{16}} \times \frac{\text{[illegible]}}{\cancel{10}} \times \frac{\cancel{18}}{\cancel{15}} = \frac{\text{[illegible]}}{10}$$

Problems: Solve:

1. $\frac{7}{8} \times \frac{1}{2} \div \frac{1}{4}$

2. $\frac{14}{16} \times \frac{5}{8}$

3. $\dfrac{\frac{2}{7} \times \frac{5}{9}}{5}$

4. $2\frac{1}{2} \times 5\frac{1}{4} \quad 3\frac{3}{8}$

5. $3\frac{1}{2} \times 4 \div 3$

6. $\frac{2}{11} \times \frac{22}{25} + \frac{1}{5}$

7. $\dfrac{\frac{1}{2} \times \frac{3}{4} \times \frac{7}{8}}{\frac{4}{5} \times \frac{5}{6}}$

8. $\dfrac{\frac{12}{16} \times \frac{7}{8} \times \frac{3}{4}}{\frac{7}{\text{[illegible]}} \times \frac{2}{\text{[illegible]}}} \times \frac{7}{3}$

9. $\frac{49}{40} \times \frac{5}{7} \div \frac{2}{5}$

10. $\dfrac{4\frac{2}{5} \times 2\frac{1}{3}}{5\frac{1}{2}}$

Practical Problems:

1. If the first and last rivets are placed $\frac{3}{4}$ in. in from the edge, find the number of rivets spaced $\frac{3}{4}$ in. apart required for a piece of 17ST of Alclad $7\frac{1}{2}$ in. long. How many are needed for $2\frac{1}{3}$ rows?

2. Determine the distance between the two outside holes if the rivet holes are spaced as given: $\frac{1}{2}'' + 5 \times \frac{3}{4}'' + 5 \times \frac{7}{8}'' + \frac{1}{2}'' = ?$ (Fig. 45).

3. If the center lines of the rivet holes form a 6-in. square, how many rivets will be required if they are placed $\frac{3}{4}$ in. apart on all four sides (Fig. 46)?

4. How long a piece of drill rod is required to manufacture 25 pins $2\frac{5}{8}$ in. long?

5. How long a piece of metal is required to manufacture 15 pieces $1\frac{3}{8}$ in. long, 21 pieces $2\frac{3}{16}$ in. long, and 8 pieces $3\frac{3}{8}$ in. long?

6. If a block is marked off with the following dimensions, how long is it? $\frac{3}{8}'' + 2\frac{1}{4}'' + 1\frac{1}{8}'' + 1\frac{5}{8}'' + \frac{7}{8}''$. If this same block has rivets placed every $\frac{5}{8}$ in., how many will be needed, using an end distance of $\frac{5}{8}$ in.?

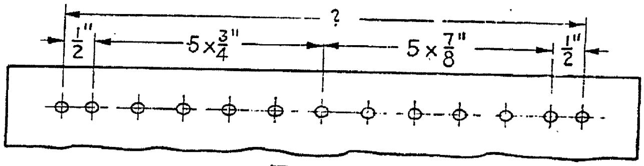


Fig. 45.

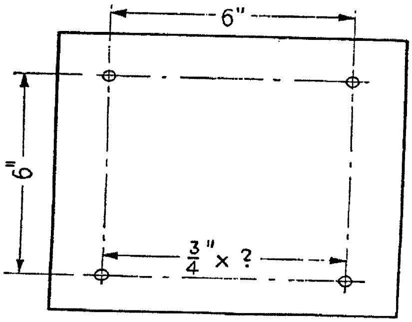


Fig. 46.

7. If a mechanic spends 2 hr. 30 min. on stacks, 1 hr. 25 min. on hydraulics, 1 hr. 10 min. on fabric repair, and 1 hr. 15 min. on seat repair, how much time is required to complete 8 hr. for that day?

8. How many holes $\frac{7}{8}$ in. center to center can be drilled in a bulb angle $10\frac{1}{2}$ in. long if $\frac{7}{16}$ in. is allowed for end distances?

DECIMAL FRACTIONS

General

Ruler measurements are accurate only to $\frac{1}{64}$ in. Although this dimension appears to be very small, a far greater degree of accuracy is required in many instances. For this accuracy, decimal fractions are used and are measured with a micrometer.

Decimal fractions are a special type of fraction whose denominator is 10 or some multiple of 10, as 100, 1,000, etc. For example, $\frac{5}{10}$, $\frac{12}{100}$, $\frac{175}{1{,}000}$ are decimal fractions.

For convenience, these fractions are written without the denominator, preceded by the required number of zeros. The number is placed to the right of the decimal point with one digit

for each cipher in the denominator. That is,

$\frac{1}{10}$ is written .1 and read one-tenth.

$\frac{1}{100}$ is written .01 and read one-hundredth.

$\frac{1}{1,000}$ is written .001 and read one-thousandth.

$\frac{1}{10,000}$ is written .0001 and read one ten-thousandth.

Examples: Read the following:

1. .5; .45
2. .96; .032
3. .756, .076
4. .1257, .0116
5. .25, .0126

Write the following:

6. 45 hundredths
7. 2 and 8 tenths
8. 15 ten-thousandths
9. 2 thousandths
10. 35 thousandths

To Reduce a Decimal Fraction to a Common Fraction

To reduce a decimal fraction to a common fraction, place the number to the right of the decimal point in the numerator, place a 1 plus a cipher for each digit in the number to the right of the decimal point in the denominator, and reduce the resulting fraction to lowest terms.

Examples: (*a*) $.3125 = \frac{3125}{10,000} = \frac{3125 \div 625}{10,000 \div 625} = \frac{5}{16}$

(*b*) $.0625 = \frac{0625}{10,000}$ Drop the 0 before the 6, and divide the top and bottom by 625.

$$.0625 = \frac{625}{10,000} = \frac{625 \div 625}{10,000 \div 625} = \frac{1}{16}$$

Problems: Reduce the following to common fractions:

1. .5
2. .25
3. .35
4. .625
5. .03125
6. .1095
7. .0265
8. .3755
9. .8125
10. .0035

To Reduce a Common Fraction to a Decimal Fraction

To reduce a common fraction to a decimal fraction, divide the numerator by the denominator, carrying the answer to the desired decimal point.

Examples: Reduce to decimal fractions:

$$(a)\ \frac{3}{4};\qquad (b)\ \frac{1}{3};\qquad (c)\ \frac{5}{16}$$

(*a*) $\frac{3}{4}$. Divide 3 by 4. Since 4 is larger than 3, it is necessary that we place a decimal point after 3 and add two ciphers.

```
    .7 5
 4/3.0 0
   2.8
     2 0
     2 0
```

4 divides into 3 evenly .75 times

(*b*) $\frac{1}{3}$. Divide 1 by 3. Since 1 is smaller than 3, it is again necessary to place a decimal point after 1 and add ciphers. This time 3 will not divide into 1 an even number of times. Therefore we carry the answer to the number of places desired.

```
    .3 3          1
 3/1.0 0  =  .33 ---
    9             3
    1 0
      9
      1
```

If the answer is carried to two places, there is a remainder of $\frac{1}{3}$. Since $\frac{1}{3}$ is less than $\frac{1}{2}$, the $\frac{1}{3}$ is dropped, giving .33. Should the answer be carried to three places, the answer would be .333.

(*c*) $\frac{5}{16}$. Divide 5 by 16 to the nearest three places.

```
     .3 1 2            8
 16/5.0 0 0  =  .312 ----
    4 8               16
      2 0
      1 6
        4 0
        3 2
          8
```

Since $\frac{8}{16} = \frac{1}{2}$, the answer would be .313.

Problems: Reduce the following common fractions to decimal fractions of three places:

1. $\frac{7}{8}$	**2.** $\frac{[illegible]}{20}$
3. $\frac{3}{4}$	**4.** $\frac{5}{8}$
5. $\frac{2}{3}$	**6.** $\frac{1}{25}$
7. $\frac{12}{16}$	**8.** $\frac{16}{24}$
9. $\frac{[illegible]}{10}$	**10.** $\frac{11}{25}$

TABLE I.—TABLE OF EQUIVALENTS

			$\frac{1}{64}$	.015625				$\frac{33}{64}$	.515625
		$\frac{1}{32}$		.03125			$\frac{17}{32}$		.53125
			$\frac{3}{64}$	.046875				$\frac{35}{64}$	.546875
	$\frac{1}{16}$			.0625		$\frac{9}{16}$			.5625
			$\frac{5}{64}$	.078125				$\frac{37}{64}$	.578125
		$\frac{3}{32}$		.09375			$\frac{19}{32}$		.59375
			$\frac{7}{64}$	.109375				$\frac{39}{64}$	.609375
$\frac{1}{8}$				.125	$\frac{5}{8}$				.625
			$\frac{9}{64}$	.140625				$\frac{41}{64}$	.640625
		$\frac{5}{32}$		.15625			$\frac{21}{32}$		.65625
			$\frac{11}{64}$	.171875				$\frac{43}{64}$	.671875
	$\frac{3}{16}$			.1875		$\frac{11}{16}$			.6875
			$\frac{13}{64}$	.203125				$\frac{45}{64}$	.703125
		$\frac{7}{32}$		.21875			$\frac{23}{32}$		.71875
			$\frac{15}{64}$	.234375				$\frac{47}{64}$	.734375
$\frac{1}{4}$				.25	$\frac{3}{4}$				.75
			$\frac{17}{64}$	.265625				$\frac{49}{64}$	.765625
		$\frac{9}{32}$		.28125			$\frac{25}{32}$		.78125
			$\frac{19}{64}$	.296875				$\frac{51}{64}$	.796875
	$\frac{5}{16}$			.3125		$\frac{13}{16}$			.8125
			$\frac{21}{64}$	.328125				$\frac{53}{64}$	.828125
		$\frac{11}{32}$		.34375			$\frac{27}{32}$		.84375
			$\frac{23}{64}$	.359375				$\frac{55}{64}$	.859375
$\frac{3}{8}$				.375	$\frac{7}{8}$				.875
			$\frac{25}{64}$	.390625				$\frac{57}{64}$	.890625
		$\frac{13}{32}$		.40625			$\frac{29}{32}$		.90625
			$\frac{27}{64}$	.421875				$\frac{59}{64}$	.921875
	$\frac{7}{16}$			.4375		$\frac{15}{16}$			.9375
			$\frac{29}{64}$	.453125				$\frac{61}{64}$	.953125
		$\frac{15}{32}$		.46875			$\frac{31}{32}$		.96875
			$\frac{31}{64}$	.484375				$\frac{63}{64}$	.984375
$\frac{1}{2}$				.5	1				1.

ADDITION OF DECIMAL FRACTIONS

Just as common fractions can be made up of mixed numbers, decimal fractions can also be made up of mixed numbers. In such a case, the whole number is placed on the left of the decimal point, as shown: 3.33; 6.75.

In adding decimal fractions, first place the decimal points of the fractions one above the other so that they form a straight column; then add, placing the decimal point in the same column as the other decimal points.

Example: Add +3.75 + 45.035 + 6.07.

$$\begin{array}{r} 3.75 \\ 45.035 \\ \underline{6.07} \\ 54.855 \end{array} \qquad \begin{array}{r} 3.750 \\ 45.035 \\ \underline{6.070} \\ 54.855 \end{array}$$

To facilitate the addition, ciphers may be added to the numbers to the right of decimal point to complete the rows of numbers.

Problems: Find the sum of:

1. 23.5 + 16.25
2. 246.43 + 105.365
3. 25.75 + 16.035
4. 5.5 + 4.25
5. 8.75 + 10.025
6. 1.728 + .075 + 10.023
7. .0076 + 1.026 + 3.05
8. 6.52 + 12.23 + 5
9. 12.42 + 10.03 + 2.56
10. 15.06 + 7.25 + 5.035

Subtraction of Decimals

The number being subtracted is called the *subtrahend,* the number that it is being subtracted from is called the *minuend,* and the answer is the *difference.* Write the numbers so that the decimal point of the minuend is directly above that of the subtrahend, and subtract as whole numbers. Place the decimal point in the difference under the other decimal points.

Should the minuend contain less digits to the right of the decimal point than the subtrahend, add ciphers to the minuend.

Example: Subtract 52.745 from 125.62.

$$\begin{array}{rl} 125.620 & \text{(minuend)} \\ \underline{-\ 52.745} & \text{(subtrahend)} \\ 72.875 & \text{(difference)} \end{array}$$

Problems: Subtract the following:

1. 215.08 − 140.25
2. 1.0 − .0065
3. 3.07 − .053
4. 25.532 − 21.15
5. 207.23 − 125.14
6. 42.070 − 37.23
7. 21.07085 − 18.0967
8. 5.25 − 2.065
9. 3.5 − 2.75
10. 15.065 − 10.0325

Multiplication of Decimals

The number being multiplied is called the *multiplicand,* the number that the multiplicand is being multiplied by is called the *multiplier,* and the answer is called the *product.*

Multiply decimals in the same way as whole numbers. Beginning at the right side of the product, point off as many decimal places as are in the multiplicand and the multiplier.

Example: Multiply 42.507 by 2.03.

```
     4 2.0 5 7   (multiplicand)
       2.0 3     (multiplier)
    -----------
    1 2 6 1 7 1
  8 4 1 1 4 0
  -------------
  8 5.3 7 5 7 1  (product)
```

Should the answer come out to more places than is practical for the mechanic, he would use the answer to the nearest number of places desired, as

For one place,	85.4
For two places,	85.38
For three places,	85.376
For four places,	85.3757

Problems: Multiply the following:

1. 8.05 × 1.750
2. 25.078 × 2.255
3. 175.395 × 10.078
4. 231 × 3.065
5. 145 × 0.235
6. 75.211 × 12.022
7. 112.123 × 15.06
8. 151.125 × 9.075
9. 5.87 × .006
10. 2.75 × 1.008

Division of Decimals

The number being divided is called the *dividend,* the number that is being divided into the dividend is called the *divisor*, and the answer is called the *quotient.* If the divisor is a mixed number, first change it to a whole number by moving the decimal point to the right in the dividend the same number of places as there are in the divisor. Then remove the decimal point from the divisor. If the dividend has not enough digits to make the above process possible, add ciphers to the right of the last figure as necessary. Now divide as for whole numbers, placing the decimal point in the quotient directly above the new decimal point in the dividend. Again, the number of decimal places in the quotient will be determined by the amount of accuracy desired.

Example: Divide 4.067 by 2.01 to the nearest four places.

```
                       2.0 2 3 3   (quotient)
(Divisor)  2.0 1/4.0 6 7 0 0 0   (dividend)
                 4 0 2
                   4 7 0
                   4 0 2
                     6 8 0
                     6 0 3
                       7 7 0
                       6 0 3
                       1 6 7
```

$$\text{Quotient} = 2.0233\,\frac{167}{201} = 2.0234, \text{ to 4 places}$$

Problems: Divide the following, to three places.

1. 130.625 ÷ 25	**2.** 84.63 ÷ 9.06
3. 14 ÷ 140	**4.** 25 ÷ .025
5. 46.23 ÷ 7.85	**6.** 1 ÷ .0675
7. 209 ÷ 14.23	**8.** .0408 ÷ 40.1
9. 283 ÷ 678	**10.** 72 ÷ .65

Practical Problems:

1. If the thickness gauges read as follows, what is the total thickness? .005, .018, .004, .011, and .0015 (Fig. 47).

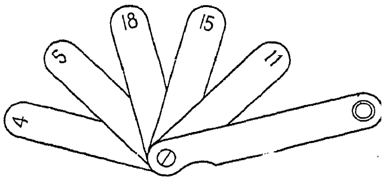


FIG. 47.—Thickness gauge (in thousandths).

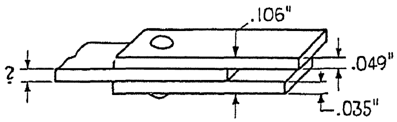


FIG. 48.

2. If three pieces of metal are riveted to give a thickness of .106 in., what would be the thickness of the third piece if the other two were .035 and .049 in. (Fig. 48)?

3. If you had 5 sheets of .035 in. and 2 sheets of .049 in., what would be the total thickness?

4. If the o.d. (outside diameter) of a ring is 1.315 in. and the i.d. (inside diameter) is 1.04 in., what is the wall thickness of the ring (Fig. 49)?

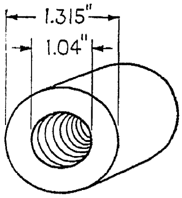


FIG. 49.

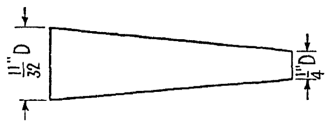


FIG. 50.

5. A tube is .5 by .035 in. What is the i.d.?

6. If two holes are drilled $\frac{1}{2}$ in. from the two sides of a $2\frac{13}{16}$-in-wide sheet of metal, what is the decimal dimension between holes?

7. A taper pin is $\frac{1}{4}$ in. diameter at the small end and $\frac{11}{32}$ in. diameter at the large end. What is the decimal difference between the two dimensions (Fig. 50)?

8. The following dimensions, in inches, add up to give the over-all length of a block. What is that length? .49 + .65 + .25 + .50 + 2.065 = ?

SQUARES AND SQUARE ROOTS

Squares

When a number is multiplied by itself, that number has been *squared*. For example, a square with 2-in. sides has a square area of $2 \times 2 = 4$ sq. in., or 2 squared = 4. To express this in a simpler way, 2 squared is written $2^2 = 4$. The superior number 2 designates how many 2's were multiplied and is called the *exponent*.

Examples: The square of 3 = 3 squared = $3^2 = 3 \times 3 = 9$
The square of 4 = 4 squared = $4^2 = 4 \times 4 = 16$
The square of 9 = 9 squared = $9^2 = 9 \times 9 = 81$

Problems: Square the following:

1. 5; 6; 7; 8
2. 15; 25; 1
3. 26; 47; 11
4. 150; 92
5. 1.04; 1.2; 1.065
6. 9.2; 10.25; 3.75

Square Root

When the process described above is reversed, *i.e.*, given the square, to find the number multiplied by itself which gave that square, the process necessary to obtain the number is called *extracting the square root*. These four words are replaced by the sign $\sqrt{}$ (called the *radical*).

The square root of 9, written $\sqrt{9}$, is 3.

The square root of the following are very simple, as they are covered by the multiplication tables:

$\sqrt{1} = 1;$	$\sqrt{25} = 5;$	$\sqrt{81} = 9$
$\sqrt{4} = 2;$	$\sqrt{36} = 6;$	$\sqrt{100} = 10$
$\sqrt{9} = 3;$	$\sqrt{49} = 7;$	$\sqrt{121} = 11$
$\sqrt{16} = 4;$	$\sqrt{64} = 8;$	$\sqrt{144} = 12$

However, extracting the square root of 456.267 is more difficult.

To Extract the Square Root of Whole Numbers and Decimals

To extract the square root of whole numbers or whole numbers and decimal fractions, follow the method outlined below:

1. Beginning at the decimal point and proceeding in both directions from the decimal point, point the figures off in groups of two by placing a small dash between the groups as shown below. Should the figures to the left of the decimal point fail to be evenly divisible into groups of two, a single number is left. Should the figures to the right of the decimal point fail to be evenly divisible into groups of two, add a cipher after the last figure.

2. Find the largest square equal to or less than the first group of numbers. In the example below the largest square for 4 is 4.

Place the square root of that number above the first group; place the square below the first group, and subtract it. The square root of 4 is 2. Therefore, place 2 above the line above 4, and place 4 below 4. Subtracting 4 from 4 gives no remainder.

3. If there is a remainder, bring it down with the next group of two figures. Multiply the present quotient by 2, and place the result in front of the new set of figures. For the example below, there is no remainder, so bring down the next group. This is 56. Multiply 2 by 2, and place opposite 56.

Disregard the last figure of the group just brought down, and, by trial, divide the multiplied number into the remaining figures. The figure given by this trial division is placed in the quotient behind the first figure and after the trial divisor. In the example, disregard the 6. By trial divide 4 into 5. It will go one time; therefore, place 1 in the quotient and 1 behind the 4, making 41. Divide 41 into 56.

4. Bring down the remainder from the above division and the next group of two numbers. Repeat the above process of paragraph 3 until an answer, to the desired decimal places, is obtained.

5. The decimal point is placed in the quotient (square root) directly above the decimal point in the dividend (square).

Example: Extract the square root of 456.267.

```
               2 1  .  3   6   0    (square root)
              /4'5 6.2 6'7 0'0 0    (square)
               4
4 1           / 5 6
                4 1
4 2 3          /1 5 2 6
                1 2 6 9
4 2 6 6         /2 5 7 7 0
                 2 5 5 9 6
4 2 7 2 0       /    1 7 4 0 0
```

Problems: Extract the square root of the following:

1. 4,692
2. 425.3
3. 26.037
4. 10,542.026
5. 72.075
6. 231.42
7. 46.0762
8. 25.25
9. 146.50
10. 11.25

To Find the Square Root of a Fraction

For fractions covered by the multiplication tables that form perfect squares, the simplest method for obtaining the square root of the number is to take the square root of the numerator and denominator.

Examples:

(a) $\sqrt{\frac{4}{9}} = \frac{\sqrt{4}}{\sqrt{9}} = \frac{2}{3}$

(b) $\sqrt{\frac{1}{4}} = \frac{\sqrt{1}}{\sqrt{4}} = \frac{1}{2}$

(c) $\sqrt{\frac{16}{144}} = \frac{\sqrt{16}}{\sqrt{144}} = \frac{4}{12}$

(d) $\sqrt{\frac{25}{81}} = \frac{\sqrt{25}}{\sqrt{81}} = \frac{5}{9}$

All the above examples are simple squares covered by the multiplication tables. However, should a complicated fraction be encountered, the easiest method of extracting the square root is to reduce the fraction to decimals and extract the square root of the decimal. The number of decimal places in the square must be twice the number desired in the square root.

Examples: $\sqrt{\frac{3}{2}} = \sqrt{1.50'00'00} = 1.224$

$\sqrt{\frac{2}{3}} = \sqrt{.66'66'67} = .816$

Problems: Extract the square root of the following fractions:

1. $\sqrt{\frac{16}{25}}$
2. $\sqrt{\frac{64}{81}}$
3. $\sqrt{\frac{25}{121}}$
4. $\sqrt{\frac{9}{16}}$
5. $\overline{\frac{49}{100}}$
6. $\sqrt{\frac{1}{6}}$
7. $\sqrt{\frac{72}{144}}$
8. $\sqrt{\frac{56}{60}}$
9. $\sqrt{\frac{9}{15}}$
10. $\sqrt{\frac{11}{15}}$

To Extract the Square Root of Mixed Numbers

To extract the square root of a mixed number, reduce the mixed number to improper fractions, and solve as above.

Example: Extract the square root of $7\frac{5}{2}$.

$$\sqrt{7\frac{5}{2}} = \sqrt{7} \times \sqrt{\frac{2}{2}} + \sqrt{\frac{5}{2}} = \sqrt{\frac{19}{2}} = \sqrt{9.5} = 3.082$$

```
              3. 0  8  2
             /9.50'00 00
              9
 608   /   50 00
           48 64
 6162   /  1 36 00
           1 23 24
             12 76
```

Problems: Extract the square root of the following mixed numbers:

1. $5\frac{2}{3}$	**2.** $10\frac{1}{4}$	**3.** $125\frac{9}{11}$	**4.** $49\frac{5}{7}$	**5.** $56\frac{5}{2}$
6. $12\frac{7}{8}$	**7.** $14\frac{2}{3}$	**8.** $60\frac{3}{7}$	**9.** $16\frac{3}{4}$	**10.** $13\frac{1}{3}$

The Addition, Subtraction, Multiplication, and Division of Square Roots

Extract the square root of the numbers under the radical, and perform the indicated process.

Example: $$\frac{2 \times \sqrt{\frac{1}{4}} + \sqrt{25}}{16} = \frac{2 \times \frac{1}{2} + 5}{} = \frac{1 + 5}{4} = \frac{6}{4} = \frac{3}{2} = 1\frac{1}{2}$$

Problems: Solve the following:

1. $\frac{1}{2} \times \sqrt{4} + \sqrt{49}$

2. $\dfrac{\frac{5}{7} \times \sqrt{\frac{36}{4}} + \sqrt{14}}{\sqrt{\frac{2}{3}}}$

3. $\dfrac{25 \times \sqrt{\frac{1}{2}} + 2\sqrt{\frac{1}{3}}}{\sqrt{3}}$

4. $\frac{3}{10} - \sqrt{\frac{7}{10}}$

5. $\dfrac{\sqrt{50} - \sqrt{25}}{4} + \dfrac{\sqrt{49} - 6}{3}$

6. $\left(\sqrt{\frac{2}{3}} - \sqrt{\frac{1}{4}}\right)\left(\sqrt{\frac{2}{5}} + \sqrt{\frac{1}{7}}\right)$

7. $3 \times \sqrt{\frac{2 \times 4}{3}}$

$\dfrac{4 \times \sqrt{\frac{1}{2}} - 2\frac{1}{3}}{\sqrt{\frac{2}{3}}}$

CUBE AND CUBE ROOTS

Cube

When a number has been multiplied by itself twice, that number has been cubed.

Examples: 3 cubed, written $3^3 = 3 \times 3 \times 3 = 27$
4 cubed, written $4^3 = 4 \times 4 \times 4 = 64$

Problems: Find the cube of the following:

1. 1; 2; 3; 4; 5
2. 6; 7; 8; 9; 10
3. 11; 12; 13; 14; 15
4. 4.5
5. 16
6. 7.5
7. 14.205
8. 11.25
9. 6.42
10. $9\frac{1}{2}$

Cube Root

When the above process is reversed, it is called *extracting the cube root.* This is designated by the radical sign and a small 3, as follows: $\sqrt[3]{\quad}$.

1. To extract the cube root, beginning at the decimal point, proceed in both directions to point off the numbers in groups of three figures each. This is done by placing a (′) between the figures as shown in the example below.

If the numbers to the left of the decimal point are not evenly divisible by 3, the remaining numbers are left in a group. If the numbers to the right of the decimal point are not evenly divisible by 3, ciphers must be added to the last figure or figures to make a group of three.

2. Obtain the highest cube that will be equal to or less than the first group of figures. This value must be the cube of one of the numbers in the multiplication table. Place the cube root of that number above the line above the first group of figures (see the example below), place the cube below the first group, and subtract.

3. Bring down the next group of three figures, placing them next to the remainder above.

To obtain a trial divisor, square the quotient above, and multiply it by 300 (see the example). Divide this figure into the new numbers. If it will go into the new number, use trial divisor, and proceed as follows: Multiply the present quotient by 30 and by the value obtained by the trial division (see the example). Add this value to the trial divisor. Now square the value obtained by the trial division, and add it to the two numbers above.

With this number as the *final divisor,* divide it into the new dividend (the remainder of the first group of figures and the second group of three figures).

Subtract and bring down the remainder with the next group of three figures.

4. Repeat the process of paragraph 3, using the new quotient each time until the cube root, to the desired number of decimal places, is obtained.

The decimal point in the cube root is placed directly above the decimal point in the cube.

Example: Extract the cube root of 1,745.337 = 1′745.337′700

	1 2 . 0 4 0	(cube root)
	1′745.337′700′000	(cube)
	1	
Trial divisor $300 \times 1^2 = 300$	745	
gives (2) $30 \times 1 \times 2 = 60$		
$2 \times 2 = 4$		
Final divisor 364	745	
	728	
Trial divisor $300 \times 12^2 = 43{,}200$	17 337	
gives (0)—bring down (700)	700	
New trial divisor $300 \times 120^2 = 4{,}320{,}000$	17 337 700	
gives (4) $30 \times 120 \times 4 = 14{,}400$		
$4 \times 4 = 16$		
Final divisor = 4,334,416	17 337 700	
	17 337 664	
This is so small that it is evident that it will give 0 as the next value.	36 000	

Problems: Find the cube root of the following to two places:

1. 1,614 2. 86.074 3. 156,749.073
4. 1,052.67 5. 114,375.25

Cube Root of Fractions and Mixed Numbers

To extract the cube root of fractions or mixed numbers, reduce them to decimals, and proceed as outlined above.

Example: Solve, to two places:

$$\sqrt[3]{10\frac{21}{32}} = \sqrt[3]{10.65625} \quad 2.20$$

	2. 2 0
	10.656′250
Trial divisor $300 \times 2 \times 2 = 1200$	2 656
gives (2) $30 \times 2 \times 2 = 120$	
No. squared $2 \times 2 = 4$	
Final divisor 1324	2 656
	2 648
Trial divisor $300 \times \overline{2\,2}^2$ 1,452,000	8 250
gives (0)	

Problems: Obtain the cube root of the following, to two places:

1. $15\frac{10}{13}$
2. $\frac{144}{156}$
3. $25\frac{5}{8}$
4. $15\frac{5}{9}$
5. $140\frac{10}{31}$
6. $125\frac{15}{21}$
7. $1{,}546\frac{11}{12}$
8. $75\frac{1}{8}$
9. $96\frac{2}{3}$
10. $54\frac{1}{4}$

ALGEBRA

General

1. Algebra is a form of mathematics whereby numbers can be replaced with letters to make it possible to express ideas in the form of equations, or formulas.

Example: The area A of a 2 in. square $= 2 \times 2$. This can be expressed in terms of the base b and altitude a, so that the same expression can be used for any square. A = area, b = length of base, and a = altitude.

$$A = b \times a$$

2. Positive and Negative Numbers.—Positive and negative numbers are used to designate numbers of opposite direction, use, etc.

Example:

$$\underline{-5 \quad -4 \quad -3 \quad -2 \quad -1 \quad 0 \quad +1 \quad +2 \quad +3 \quad +4 \quad +5}\,{}^{B}$$

Given the line AB, divided as shown from the center. In such a case, the positive numbers indicate movements to the right and the negative numbers indicate movement to the left from the center.

If a man should gain \$5 and then lose \$5, his net gain is 0. The gain would be $+5$, and his loss would be -5.

Sometimes the $+$ sign is omitted from positive numbers, as $+x = x$. The negative sign can never be omitted from negative numbers.

3. Absolute Value.—The absolute value of a number is the arithmetical value of the number without reference to its sign. Thus, the absolute value of -5 is 5, and the absolute value of $+5$ is 5.

4. To add two numbers having like signs, add their absolute values, and place the common sign in front of the sum, as

$$(+4) + (+2) = +6; \qquad (-5) + (-2) = -7$$

5. To add two numbers having unlike signs, subtract the smaller absolute value from the larger, and place the sign of the larger in front of the answer, as

$$(+3) + (-2) = +1; \qquad (-5) + (+2) = -3$$

6. To subtract one number from another, change the sign of the subtrahend, and add the results to the minuend, as

$$\begin{aligned}(+6) - (+4) &= +6 - 4 = +2\\(-5) - (+3) &= -5 - 3 = -8\\(-5) - (-2) &= -5 + 2 = -3\end{aligned}$$

7. To multiply two numbers, multiply their absolute numbers; the product is positive if the numbers have like signs, and negative if the numbers have unlike signs. That is,

Positive × positive = positive
Negative × negative = positive
and Positive × negative = negative

$$(+5) \times (+2) = +10; \qquad (-6) \times (-4) = +24$$
$$(-5) \times (+5) = -25; \qquad (+7) \times (-3) = -21$$

8. To divide one number by another, obtain the quotient of their absolute values; make it positive if the signs of the two numbers are like and negative if the signs of the two numbers are unlike. That is,

Positive ÷ positive = positive
Negative ÷ negative = positive
and Positive ÷ negative = negative

Problems: Solve the following:

1. $(+3) \times (+15)$
2. $(+4) + (+3)$
3. $(+15) - (+5)$
4. $(+10) \div (-2)$
5. $(+10) - (+2) \div (-4)$
6. $(-5) \times (+2) + (-3) \div (-1)$
7. $[(-25) \quad (+5)] \times (-20)$
8. $\left(\frac{+25}{-5}\right) \times (+2)$
9. $\left(\frac{-10}{+3}\right) \times (-3)$
10. $\left(\frac{+15}{+5}\right) \times \left(\frac{-10}{+2}\right)$

9. Factors.—If two or more numbers are multiplied, each is a *factor* of the product; also, the product of two or more of these numbers is a factor of the product.

Thus, 2, 4, and 6 are factors of 48; 8 is a factor of 48; 12 is a factor; and 24 is a factor.

10. Powers, Exponents, and Roots.—The product of two or more equal factors is called a *power*, as

$$2 \times 2 = 4; \qquad (a) \times (a) = a^2; \qquad (xy) \times (xy) = x^2y^2$$

The superior number at the right hand of a factor is called the *exponent* and tells how many equal factors are to be multiplied together, as 3^2, 8^3, and 4^4. In the case of letters, the exponent of the product is obtained by adding the exponents of the factors, as

$$(x) \times (x) = x^2; \qquad (x^2) \times (x) = x^3; \qquad (x^2) \times (x^5) \times (x) = x^8$$

One equal factor of a power is called the *root* of that power. Thus,

2 is the square root of $2 \times 2 = 4$

or 3 is the cube root of $3 \times 3 \times 3 = 27$

11. Coefficient.—Any factor of a product is called the *coefficient* of the product of the remaining terms. Thus, in $2ab$, 2 is a coefficient of ab, a is a coefficient of $2b$, and b is a coefficient of $2a$.

12. Literal Factors and Like Terms.—Where the coefficient of a product contains letters instead of numbers, the letters are called *literal factors*, as $2ab$, $3xy$, etc.

Terms that have the same literal factors are called *like terms*. That is, $2x^2y$ and $-4x^2y$ are like factors, but $2x^2y^2$ and $-2x^2y$ are not like factors, because the second term does not contain a y^2 term.

13. To add similar terms having like signs, add the absolute value of the numerical coefficient, affix the common letters, and prefix the common sign to the results.

Examples: Add:

1. $+2ab;\ +3ab;\ +7ab$

$$\begin{array}{r} +2ab \\ +3ab \\ +7ab \\ \hline +12ab \end{array}$$

2. $+7xy;\ +4xy;\ +5xy$

$$\begin{array}{r} +7xy \\ +4xy \\ +5xy \\ \hline +16xy \end{array}$$

3. $+2x\ +3y\ +6xy\ +2y\ +4x\ +2xy$

$$\begin{array}{rrr} +2x & +6xy & +3y \\ +4x & +2xy & +2y \\ \hline +6x & +8xy & +5y \end{array} = (+6x) + (+8xy) + (+5y)$$

14. To add similar terms having unlike signs, collect the terms having like signs; add as above, and subtract the absolute value of the smallest sum from the largest sum, affixing the common letters and prefixing the sign of the largest. This is called *algebraic addition.*

Examples: Add:

1. $+2xy \quad -3xy \quad +4xy \quad -xy$

$$\begin{array}{rr} +2xy & -3xy \\ +4xy & -\ xy \\ \hline +6xy & -4xy \\ -4xy & \\ \hline +2xy & \end{array}$$

2. $+x^2 \quad -3x^2 \quad +2x^2 \quad -5x^2$

$$\begin{array}{rr} +x^2 & -3x^2 \\ +2x^2 & -5x^2 \\ \hline +3x^2 & -8x^2 \\ & +3x^2 \\ \hline & -5x^2 \end{array}$$

3. $2xy - 3xy + 2x^2 - 2y^2 - x^2 + y^2$

$$\begin{array}{rrr} -3xy & +2x^2 & -2y^2 \\ +2xy & -\ x^2 & +\ y^2 \\ \hline -\ xy & +\ x^2 & \end{array}$$

y^2

Problems: Add the following:

1. $+2x + 2y + 3x + 4y$
2. $+2x - 2y + x - 4y$
3. $2xy + 2x^2 - x^2 + 2y^2 - 2y^2$
4. $4x + 2ax - x - 3ax$
5. $6y^2 + 2xy + 3xy - x^2$
6. $3ab + a^2 - b^2 + ab$
7. $2cx - 4x + 3cx + 5x$
8. $2x^2 - x^2 + 2y^2 - 3y^2$
9. $2xy^3 - 2x^2y - xy^3 + x^2y$
10. $x^2 + 2xy^2 - x^2 + xy^2 - 2xy^2$

Use of Parentheses and Multiplication of Algebraic Quantities

1. The expression $(a) + (x - y)$ means that a must be added to both x and $-y$, or $a + x - y$. Also,

$$(x + y) + (x - 2y) = x + y + x - 2y = 2x - y.$$

2. The expression $(c) - (x + y)$ means that x and $-y$ must be subtracted from c, or $c - x - y$. Also,

$$(2x + y) - (x - y) = 2x + y - x + y = x + 2y.$$

The rules covering the addition above are as follows:

1. When removing parentheses preceded by a plus sign, without changing signs of terms within parentheses, remove parentheses and add.

2. When removing parentheses preceded by a negative sign, change the signs of the terms within the parentheses, remove the parentheses, and add algebraically.

3. The expression $(x - y)(x + y)$ means that $x - y$ is to be multiplied by $x + y$. Since the product of multiplication is the same regardless of the order in which the factors were multiplied, the factors are placed one below the other and multiplied as if they were whole numbers, the rule of multiplication of signs being observed.

Example 1: $(x - y)(x + y)$

$$\begin{array}{rrrl} & x & -y & \\ & x & +y & \\ \hline & +xy & -y^2 & \\ & -xy & & +x^2 \\ \hline & 0 & -y^2 & +x^2 = x^2 - y^2 \quad \text{(better form)} \end{array}$$

First multiply $-y$ by $+y$, giving $-y^2$; then multiply $+x$ by $+y$, giving $+xy$. This is the first set of terms. Now multiply $+x - y$ by $+x$, giving $-xy + x^2$. Like terms are placed together and added algebraically.

Example 2: $(x + y)(2x - y)$

$$\begin{array}{rrrl} & x & +y & \\ & 2x & -y & \\ \hline & -xy & & \\ & +2xy & & +2x^2 \\ \hline & +xy & -y^2 & +2x^2 = 2x^2 + xy - y^2 \end{array}$$

Problems: Multiply the following:

1. $a \times a^2 \times a^5$

2. $2a^2 \times 3ab$

3. $(-5b) \times (+2ab)$

4. $15x \times (-2x) \times (-1x)$

5. $2x - 3x(4x) - 2y(x^2)$

6. $(2x - 36 (x + y)$

7. $(5x + y)(x + 2y)$

8. $(4a + 3y)(2a - y)$

9. $-5a(a - b)(a + b)$

10. $(x^2 - y^2)(x + y)$

Division of Algebraic Quantities

The division of algebraic quantities requires the following three steps:

1. Divide the absolute numerical value of the dividend by the absolute numerical value of the divisor. The result is the absolute numerical value of the quotient.

2. Subtract the exponents of the letters of the divisor from the exponents of the *same* letter in the dividend. This gives the exponents for the letter quotient. Affix the letter quotient to the numerical quotient.

3. Observing the law of signs given previously, prefix the correct sign.

Example 1: Divide $4x^3y^2$ by $2xy$.

$$\frac{4}{2} = 2; \qquad \frac{x^3}{x} = x^{3-1} = x^2;$$

$$2x^2y, \qquad \text{or, by cancellation,} \qquad \frac{\overset{2}{\cancel{4}}x^{\overset{2}{\cancel{3}}}y^{\cancel{2}}}{} \qquad 2x^2y \qquad \textit{Ans.}$$

Example 2: Divide $-12a^2x^2y^3$ by $6ax$.

$$\frac{-\overset{2}{\cancel{12}}a^{\cancel{2}}x^{\cancel{2}}y^3}{} = -2axy^3$$

Example 3: Divide $x^2 + 2xy + y^2$ by $x + y$.

$$\begin{array}{l}
\underline{x + y/}x^2 + 2xy + y^2\underline{/x + y} \\
\qquad\;\; \underline{x^2 + xy} \\
\qquad\qquad\; + xy + y^2 \\
\qquad\qquad\; \underline{+ xy + y^2}
\end{array}$$

Divide $x + y$ into $x^2 + 2xy + y^2$ in the same manner as for whole numbers. First, find how many times x will go into x^2. The answe is x times. Therefore, place x in the quotient, and multiply $x + y$ by x. This gives step (1) or $x^2 + xy$; place them under like terms. Now change signs, and add. The remainder is $xy + y^2$. Divide x into xy. It will go $+y$ times; therefore, place $+y$ in the quotient, and multiply $x + y$ by $+y$. This will give $xy + y^2$. Place these terms below like terms, change signs, and add. There is no remainder. Therefore, $x + y$ and $x + y$ are factors of

$$x^2 + 2xy + y^2,$$

and the division may be called *factoring*.

Problems in Division:

1. $y^5 \div y^2$
2. $(-10xy^4) \div 2xy$
3. $(-14c^3) \div (-2c)$
4. $(-4a^2 + 8a) \div (-2a)$
5. $(x^2 - 7x + 12) \div (x - 4)$
6. $(6x^2 + 11xy - 10y^2) \div (2x + 5y)$
7. $(15x^2 - 11x - 14) \div (3x - 2)$
8. $(6x^4 - 3x^3 + 9x^2) \div (-3x^2)$
9. $(x^3 - 8y^3) \div (x - 2y)$
10. $(1 - 81m^4) \div (1 + 3m)$

Factoring

To factor an expression is to find two or more expressions whose product is the original expression.

Factors must not contain any radical signs.

1. A number or an expression that does not contain any factor except itself and 1 is called a *prime factor*.

2. A monomial factor is a number that will divide evenly into each term of an expression, as 25 below:

$$25x^2 + 25xy + 25y^2 = 25(x^2 + xy + y^2)$$

3. Complete factoring consists in the following:
a. Remove all monomial factors from the expression.
b. Obtain the prime factors of the results if possible.

Examples:

1. $12x^2 - 12y^2 = 12(x^2 - y^2) = 12(x + y)(x - y)$
2. $4x^2 + 8xy + 4y^2 = 4(x^2 + 2xy + y^2) = 4(x + y)(x + y)$
3. $2ax^2 - 4axy + 2ay^2 = 2a(x^2 - 2xy + y^2) = 2a(x - y)(x - y)$

Problems: Factor the following:

1. $5y^3 - 10y^2 + 5y$
2. $12a^2b - 16ab^2$
3. $x^4 - y^4$
4. $x^2b + 8xb - 33b$
5. $x^6 - y^6$
6. $x^4 - 16$
7. $a^3 + 3a^2b + 3ab^2 + b^3$
8. $x^3 - 11x^2 + 39x - 45$
9. $x^3 + 7x^2 + 16x + 12$
10. $18x^3$

Simple Equations

An equation is a statement that two quantities are equal. For example, $5x = 20$ states that $5x$ and 20 are equal to each other.

1. Members.—The part of an equation that is to the left of the equality sign is called the *first member*, the *left side*, or the *left-hand member*. The part of the equation that is on the right side of the equality sign is the *second member*, *right side*, or *right-hand member*. In the equation above, $5x$ is the first, or left-hand, member, and 20 is the second, or right-hand, member.

An equation is used to find the value of an unknown number from its relationship with known numbers. Unknown numbers are usually represented by letters as x, y, and z, that is, by letters at the end of the alphabet. Known numbers are represented by a, b, or c, that is, by letters at the beginning of the alphabet.

2. Axioms.—The solution of equations is governed by the following rules:

1. Equal numbers added to equal terms give equal sums.

If $x + y = 20$, then $(x + y) + 5 = 25$

2. Equal numbers subtracted from equal terms give equal remainders.

If $x + y = 20$, then $(x + y) - 2 = 18$

3. Equal terms multiplied by equal numbers give equal products.

If $x + y = a + b$, then $\quad 2x + 2y = 2a + 2b$

4. Equal terms divided by equal numbers give equal quotients.

If $x + y = a - b$, then $\dfrac{x + y}{} = \dfrac{a - b}{}$

3. To transfer a term from one side of the equation to the other is called *transposition*. A term can be changed from one side of the equation to the other by changing the signs of the transposed term.

If $a + x = b$, then $\qquad x = b - a$

The signs of every term of an equation may be changed without affecting the equality.

If $a + x = b$, then $\qquad -a - x = -b$

4. For the solution of simple equations, collect by transposition all known terms to the right side of the equation and all unknown terms to the left side of the equation.

Examples:

1. $4x - 1 = 2x + 3$

$4x - 2x = 3 + 1$

Combining like terms, $\qquad 2x = 4$

Dividing both sides by the coefficient of x, $\qquad x = 2$

2. $2(x - 1) = 3(x - 5)$

Simply, $\qquad 2x - 2 = 3x - 15$

Transposing, $\qquad 2x - 3x = -15 + 2$

Combining, $\qquad -x = -13$

Change sign. $\qquad x = 13$

3. $2ax = b + c + ax$

$2ax - ax = b + c$

$ax = b + c$

$$x = \frac{b + c}{a}$$

4. $ax + 2b = bx + c$

$ax - bx = c - 2b$

$x(a - b) = c - 2b$

$$x = \frac{c - 2b}{a - b}$$

Problems: Solve the following equations:

1. $5x = 10 + 4x$
2. $10x - 2 = 8 - 2x$
3. $2(5x - 2) = 4(x + 5)$
4. $3ab - ax = 2$
5. $2ab - ax = -6x^2 + 12bx$
6. $\frac{3x}{b} = a - c$
7. $3x^2 + 3 = 15$
8. $2x^2 - 12 = x^2 + 24$
9. $10x^2 - 2 = 2x^2 + 6$
10. $ax + b = cx + d$

5. Simple Equations Involving Fractions.

Examples:

1. $\frac{(-7x)(-3a)}{-84ax} \quad 3x$

$\frac{+\cancel{21}\cancel{a}\cancel{x}}{-4} = 3x$

$-\frac{1}{4} = 3x$

$x = -\frac{1}{12}$

2. $-\frac{5b(-6c)}{(-2c)(-15b)} = 3x$

$-\frac{-30bc}{+30bc} \quad 3x - 5$

$\frac{30bc}{30bc} = 1 = 3x - 5$

$3x \quad 1 + 5$

$x = 2$

3. $-\frac{(-5a^2)(-7y^2)}{(+2y)(+7a^2)} = 10$

$-\frac{+\overset{5}{\cancel{35}}\cancel{a^2}\overset{y}{\cancel{y^2}}}{+\underset{2}{\cancel{14}}\cancel{a^2}\cancel{y}} = 10$

$-\frac{5y}{2} = 10$

$y = -\frac{20}{5} \quad -4$

4. $\frac{2y - \frac{1}{2}}{y^2 - \frac{1}{4}y} = 1$

$\frac{\frac{4y - 1}{2}}{\frac{4y^2 - 1y}{4}}$

$\frac{4y - 1}{\cancel{2}} \times \frac{\overset{2}{\cancel{4}}}{4y^2 - 1y} = 1$

$\frac{2(4y - 1)}{y(4y - 1)} = 1$

y

5. $\frac{\frac{x - 1}{x + 2}}{x} = \frac{x(x + 1)}{x + 6}$

Invert the fraction on the left side, and multiply.

$$(x - 1) \quad x + 2 \quad \frac{x(x + 1)}{x + 6}$$

Divide both sides by x.

$$\frac{(x - 1)\cancel{x}}{(x + 2)\cancel{x}} = \frac{\cancel{x}(x + 1)}{\cancel{x}(x + 6)}$$

Obtain the least common denominator, and multiply.

$$\frac{(x - 1)(x + 6)}{(x + 2)(x + 6)} = \frac{(x + 1)(x + 2)}{(x + 2)(x + 6)}$$

Multiply, and collect terms, the common denominator dropping out because common to both sides.

$$\begin{aligned} x^2 - x + 6x - 6 &= x^2 + x + 2x + 2 \\ x^2 - x^2 + 5x &= 3x - 6 - 2 = 0 \\ +2x - 8 &= 0 \\ x &= 4 \end{aligned}$$

From the above examples, it is seen that it is necessary to complete the indicated processes of the numerator and denominator before solving the equation. That is, multiplication, division, addition of like terms, and subtracting like terms should be performed before dividing the numerator by the denominator or before obtaining the least common denominator.

Problems: Solve the following:

1. $\frac{2-x}{5x} \quad \frac{4}{15x} \quad \frac{1}{6}$

2. $\frac{x-5}{x+3} - \frac{x-4}{x+6}$

3. $\frac{1}{4x} + \frac{1}{2x-2} = \frac{2}{x(x-1)}$

4. $\left(\frac{x+5}{x-3}\right)(2x) = \frac{-x(8)}{(x-3)} + 10x$

5. $\dfrac{\frac{4+x}{1-x}}{\frac{1}{1-x}} \quad 12$

6. $5 - x \quad \frac{1}{x-1}$

7. $\frac{4x}{x(x-5)} \quad \frac{-5x^2}{x(4x+x^2)}$

8. $\frac{}{z-4} - \frac{}{3z-12} - 2$

6. Equations Involving Two Unknowns.—All the foregoing equations contained only one unknown. Many cases arise where it is necessary to solve equations involving two unknowns or more. For each unknown, there must be an equation to make solution possible.

Examples:

1. $x + y = 14$
$3x + 2y = 12$

First find a value of x in terms of y by transposition.

$$x = 14 - 4y$$

Substitute this value of x in the second equation.

$$\begin{aligned} 3(14 - 4y) + 26 &= 12 \\ 42 - 12y + 2y &= 12 \end{aligned}$$

Collect and transpose terms; then solve for y.

$$\begin{aligned} -12y + 2y &= -42 + 12 \\ -10y &= -30 \end{aligned}$$

Change signs on both sides.

$$10y = 30$$
$$y = 3$$

Substitute the value of y in the first equation, and solve for x.

$$x + 4(3) = 14$$
$$x + 12 = 14$$
$$x = 2$$

2. $\frac{2x}{3} + \frac{3y}{4} = -\frac{7}{2}$

$\qquad \frac{2y}{5} \qquad \frac{11}{2}$

First clear fractions in both equations by obtaining the least common denominator.

$$\frac{8x}{12} + \frac{9y}{12} = -\frac{42}{12}$$

Multiply both sides of the equation by 12.

$$8x + 9y = -42$$

Repeating the process for the second equation,

$$\frac{5x}{20} - \frac{8y}{20} = \frac{110}{20}$$
$$5x - 8y = 110$$

Using the first equation, find a value for x in terms of y by transposition.

$$8x + 9y = -42$$
$$x = -\frac{9y}{8} - \frac{42}{8}$$

Substitute this value for x in the second equation.

$$5x - 8y = 110$$
$$5\left(-\frac{9y}{8} - \frac{42}{8}\right) - 8y = 110$$
$$-\frac{45y}{8} - \frac{210}{8} - 8y = 110$$

Multiply both sides of the equation by 8, and solve for y.

$$-45y - 210 - 64y = 880$$
$$-109y = 1{,}090$$
$$y = -10$$

Using this value for y, solve the value of x in the first equation.

$$8x + 9(-10) = -42$$
$$8x - 90 = -42$$
$$x = \frac{48}{8} = 6$$

3. $x^2 + y^2 = 85$
$x - y = 1$

Using the second equation, obtain a value of x in terms of y by transposing.

$$x = 1 + y$$

Substitute this value of x in the first equation.

$$\begin{aligned} (1 + y)^2 + y^2 &= 85 \\ 1 + 2y + y^2 + y^2 &= 85 \\ 2y^2 + 2y &= 85 - 1 \end{aligned}$$

Collecting all terms on one side, set the new equation equal to zero, and factor.

$$2y^2 + 2y - 84 = 0$$

Divide both sides by 2.

$$y^2 + y - 42 = 0$$

Factoring,

$$(y + 7)(y - 6) = 0$$

Setting each factor equal to zero, solve for y.

$$\begin{aligned} y + 7 &= 0 \\ y &= -7 \\ y - 6 &= 0 \\ y &= 6 \end{aligned}$$

e for two values of x

$$\begin{aligned} x - (+6) &= 1 \\ x = 1 + 6 &= 7 \\ x - (-7) &= 1 \\ x + 7 &= 1 \\ x = -7 + 1 &= -6 \end{aligned}$$

In the first two examples, because x and y were linear there was only one possible answer for x and y. In the last example, however, because of the squared terms, there were two possible answers for both x and y.

Problems: Solve the following:

1. $2x + y = 7$
$2x - y = 5$

2. $3x + y = 11$
$-3x + 2y = -5$

3. $x - y = 5$
$x - 2y = 2$

4. $4x + 3y = 0$
$y - x = 7$

5. $\frac{1}{x} - \frac{1}{y} = \frac{1}{xy}$
$\frac{2}{x} - \frac{4}{y} = -\frac{2}{xy}$

6. $2x + \frac{3}{y} = -5$
$4x - \frac{3}{y} = 8$

7. $x - y = 10$
$x + y = 9$

8. $x^2 - y^2 = 28$
$x - y = 2$

ANGULAR MEASUREMENT

General

An angle may be defined as the portion of an arc included between two intersecting lines. That is, all intersecting lines intersect at a definite angle to each other. Figure 51*a*, *b*, and *c* furnishes examples.

The point O of the angle in Fig. 51 is called the *vertex*, and the lines AO and BO are called the *sides*. An angle is defined by giving the letters in the following order: AOB or BOA. The letter representing the vertex must always be in the center.

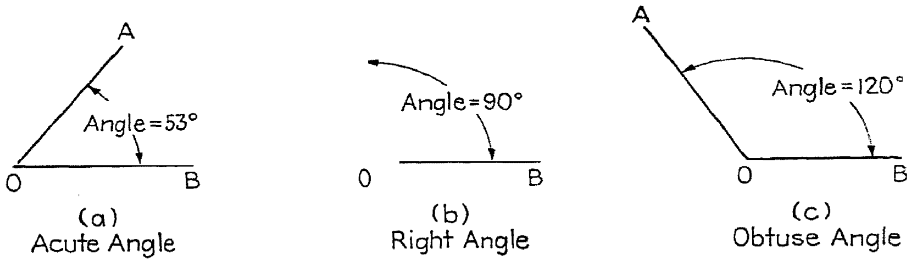


FIG. 51.—Three types of angles.

Just as the scale, ruler, or micrometer is used to measure length, height, and width, the protractor is used to measure angles (Fig. 52), the unit of measure being degrees, minutes, and seconds. One degree is equal to 60 minutes, and one minute is equal to 60 seconds. A circle is divided into 360°; half the circle or a straight line (the diameter) is 180°; and one-quarter of the circle is 90°.

The angle AOB in Fig. 52 can be determined in the following manner: Layout work, requiring angular measurement, can easily be performed with a protractor as shown in Fig. 52*b*. However, if the object has been manufactured, it is sometimes impossible to determine the angle by this simple means. In such cases, a level protractor is used (Fig. 53). This instrument has a rotating protractor with a bubble level. To obtain angles with this instrument, place the instrument against the object, as the wing spar in Fig. 53; rotate the protractor until the bubble is centered; and read the angle from the index.

When a level protractor is not available, it is possible to determine such angles by means of the ratios that exist between the

sides of any right triangle and its angles. The study of the relationship between distances and angles is called *trigonometry.*

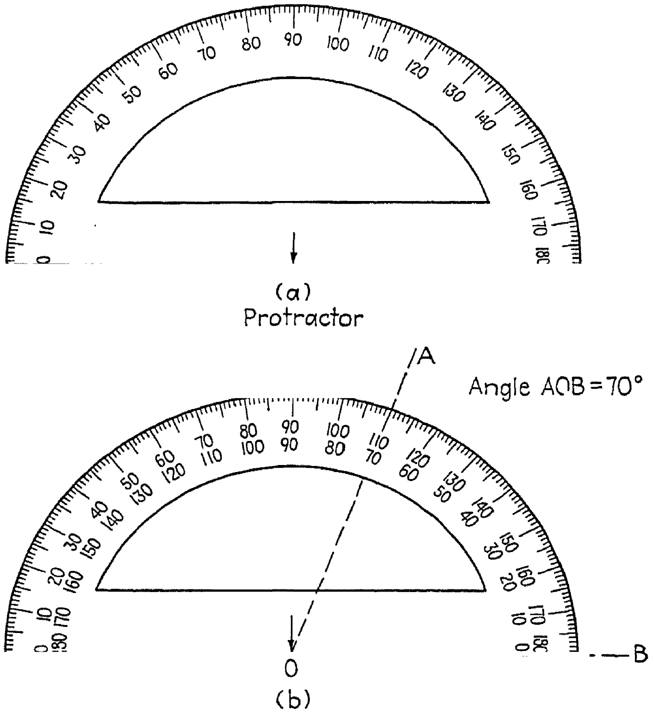


FIG. 52.—(*a*) Protractor, (*b*) use of protractor.

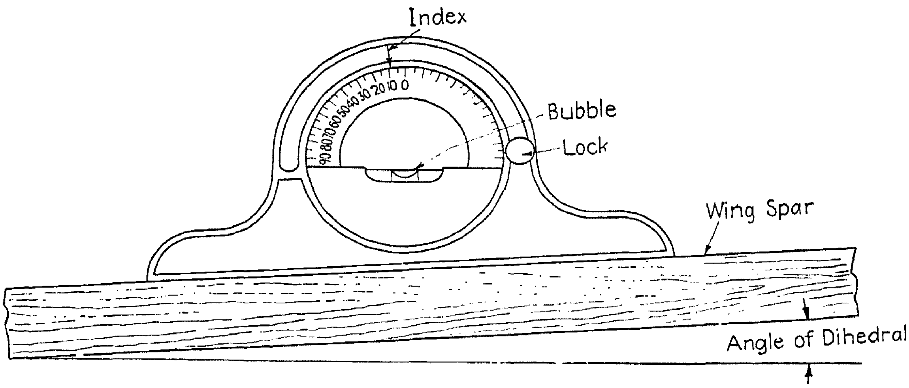


FIG. 53.—Level protractor.

This course will not attempt to cover the subject matter completely but will furnish enough information to solve simple problems of dihedral, etc.

The Right Triangle

Before proceeding, some facts about right triangles will be reviewed.

1. As just stated, angles are always designated by three letters, the center letter being the letter at the vertex. Therefore, the right triangle in Fig. 54 has three angles as follows:

$$\angle CAB; \qquad \angle CBA; \qquad \angle ACB$$

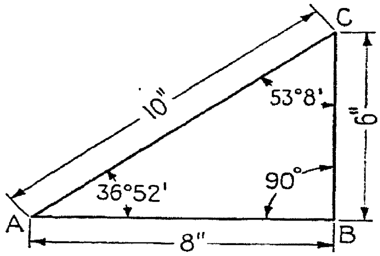


Fig. 54.—Right triangle.

2. The sum of the three angles of any triangle is 180°.

3. The sides of a triangle are designated by the letters at the two ends of the line. Therefore, the sides of the triangle above are

$$AB; \qquad BC; \qquad CA$$

4. The side opposite the right angle is always called the *hypotenuse.* Since side AC is opposite angle ABC, it is the hypotenuse of the given triangle.

5. Side AB is opposite to angle ACB and *adjacent to* angle CAB. Side CB is opposite to angle CAB and *adjacent to* angle ACB.

6. The sum of the squares of the two adjacent sides of a right triangle is equal to the square of the hypotenuse. That is,

$$\overline{AB}^2 + \overline{CB}^2 = \overline{AC}^2 \tag{1}$$

or

$$AC = \sqrt{\overline{AB}^2 + \overline{CB}^2}$$

Trigonometric Functions

The ratio between the angles and the sides of a triangle is called *trigonometric function.* There are six possible ratios, or trigonometric functions, for each angle of a triangle. This text will deal only with the tangent. Using the right triangle given above, the tangent is equal to the ratio of the

$$\frac{\text{side opposite the angle}}{\text{side adjacent to the angle}}.$$

TABLE II.—NATURAL TANGENTS

Angle, deg.	Tangent	Angle, deg.	Tangent	Angle, deg.	Tangent	Angle, deg.	Tangent
0	.00000	23	.42447	45	1.00000	68	2.47509
1	.01746	24	.44523	46	1.03553	69	2.60509
2	.03492	25	.46631	47	1.07237	70	2.74748
3	.05241	26	.48773	48	1.11061	71	2.90421
4	.06993	27	.50953	49	1.15037	72	3.07768
5	.08749	28	.53171	50	1.19175	73	3.27085
6	.10510	29	.55431	51	1.23490	74	3.48741
7	.12278	30	.57735	52	1.27994	75	3.73205
8	.14054	31	.60086	53	1.32704	76	4.01078
9	.15838	32	.62487	54	1.37638	77	4.33148
10	.17633	33	.64941	55	1.42815	78	4.70463
11	.19438	34	.67451	56	1.48256	79	5.14455
12	.21256	35	.70021	57	1.53986	80	5.67128
13	.23087	36	.72654	58	1.60033	81	6.31375
14	.24933	37	.75355	59	1.66428	82	7.11537
15	.26795	38	.78129	60	1.73205	83	8.14435
16	.28675	39	.80978	61	1.80405	84	9.51436
17	.30573	40	.83910	62	1.88073	85	11.4301
18	.32492	41	.86929	63	1.96261	86	14.3007
19	.34433	42	.90040	64	2.05030	87	19.0811
20	.36397	43	.93252	65	2.14451	88	28.6363
21	.38386	44	.96569	66	2.24604	89	57.2900
22	.40403	..	......	67	2.35585	90	Infinite

Then for angle CAB the tangent (written tan A) is

$$\frac{\text{Opposite side}}{\text{Adjacent side}} = \frac{CB}{AB} = \frac{6}{8} = .75 \qquad (2)$$

and $$\tan C = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{AB}{CB} = \frac{8}{6} = 1.333 \qquad (3)$$

This ratio between the sides will continue to exist no matter how large the sides are made. For example, increase the length of the sides as in Fig. 55, and calculate the ratio again. Then, if

$$\tan A = \frac{CB}{AB} = \frac{6}{8} = \frac{9}{12} = \frac{12}{16} = .75$$

and $$\tan C = \frac{AB}{CB} = \frac{8}{6} = \frac{12}{9} = \frac{16}{12} = 1.333$$

the ratio has remained the same.

By calculating these ratios for a large number of triangles, then measuring the angle that the ratios give, and listing this information in tabular form, it would be possible to solve any right triangle. This information is given in Table II.

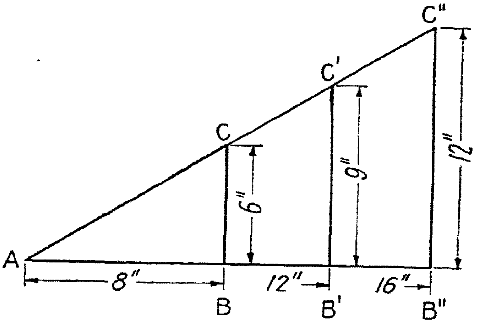


FIG. 55.—Right triangles with same angles but larger sides.

USE OF TABLES

By using the tables the angles CAB and ACB can be obtained. To find angle CAB, look in the table for the angle whose tangent is .75. The tangent of 36° is .72654, and the tangent of 37° is .75355. Subtracting .72654 from .75355 gives a remainder of .02701, the amount required to give a change of 1°. Divide this value by 60 to obtain the change required per minute. This change

.7 5 3 5 5	(tan of 37°)
.7 2 6 5 4	(tan of 36°)
6 0/.0 2 7 0 1 /	(for change of 1°)
2 4 0 / .0 0 0 4 5	(for change of 1′)
3 0 1	
3 0 0	

is .00045.

Subtract .72654 from .75000. The remainder is .02346. Divide .02346 by .00045 to determine the number of minutes .75000 is greater than the tangent of 36°.

$$\frac{.02346}{.00045} = 52'$$

Therefore, angle CAB equals 36°52′. This process is called *interpolation.*

Angle ACB can be found in the same manner.

Problems:

1. Given the right triangle ABC. Side AB is 15 in., and side CB 8 in. The hypotenuse is side AC. Find side AC and angles CAB and ACB.

2. Given the wing in Fig. 56 with the dimensions as shown. Find the wing span and the dihedral angle.

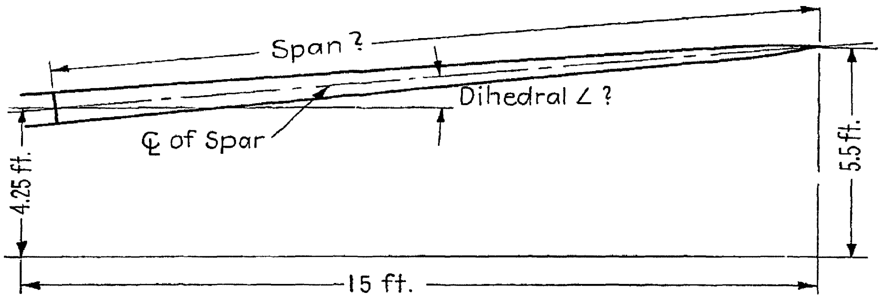


FIG. 56.—Find dihedral ∠ of wing.

3. Given Fig. 57. Find the geometric chord length and the angle it makes with the ground.

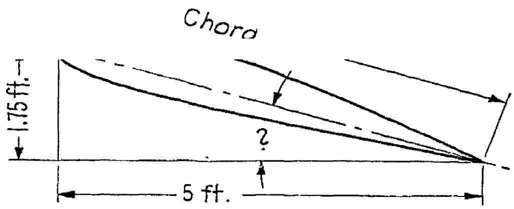


FIG. 57.

4. Find the angles between the center lines of the tube cluster shown in Fig. 58.

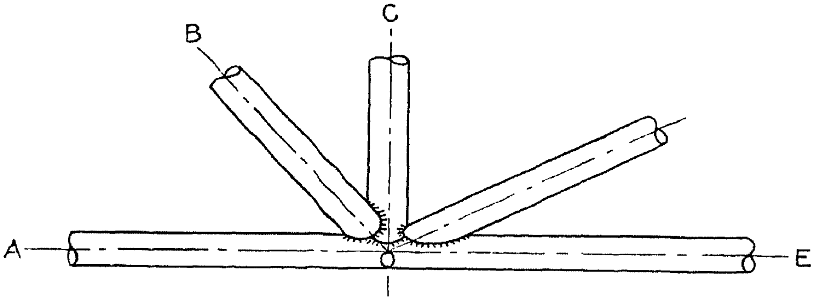


FIG. 58.—Tube cluster.

MEASUREMENT OF PERIMETER, CIRCUMFERENCE, AREA, AND VOLUME

PERIMETERS

General.—The *perimeter* of an object is the distance around that object, as shown in Fig. 59, or the sum of the length of all its sides.

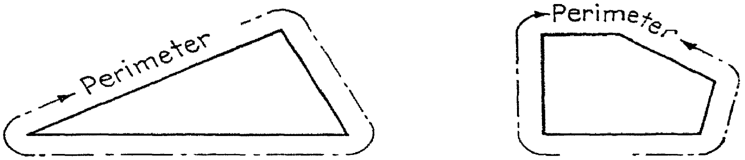
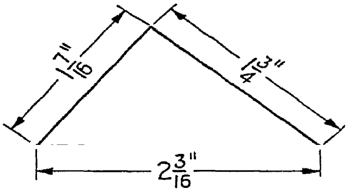


FIG. 59.—Perimeters.

Examples: Find the perimeters of the following:

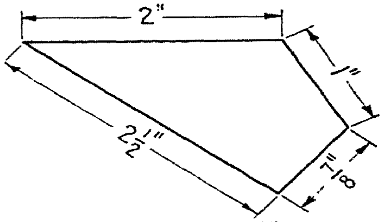
1.



$P = 1\frac{7}{16}'' + 2\frac{3}{16}'' + 1\frac{3}{4}'' = 5\frac{3}{8}''$

FIG. 60.—Perimeter of triangle.

2.



$P = 2'' + 2\frac{1}{2}'' + \frac{7}{8}'' + 1'' = 6\frac{3}{8}''$

FIG. 61.—Perimeter of an irregular object.

Problems: Find the perimeters of the following:

1.

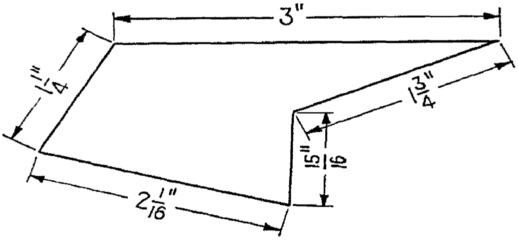


FIG. 62.

2.

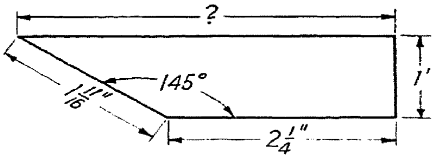


FIG. 63.

3.

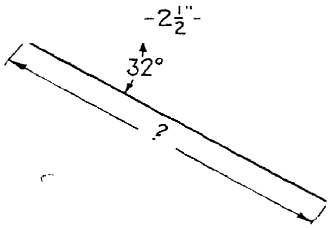


FIG. 64.

The *circumference* of a circle is the distance around the circle and equal to

$$C = 2\pi R = \pi D \tag{4}$$

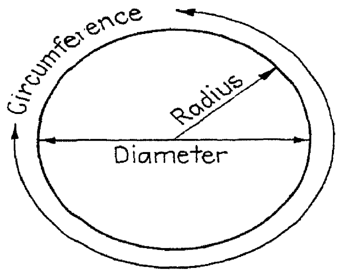


FIG. 65.—A circle.

where C = circumference
R = radius of the circle, or distance from the center to the circumference
D = diameter = $2 \times R$, or length of a straight line drawn through the center of the circle and meeting the circumference at both ends
π = 3.1416, called *pi*. The diameter of any circle divided into its circumference will go 3.1415926+ times. This constant is shortened to read 3.1416 for all practical purposes.

Example:

(*a*) Find the circumference of a circle whose diameter is 3 in.

$$C = \pi D = 3.1416 \times 3 = 9.4248 \text{ in.}$$

(*b*) Find the circumference of a circle with a 2 in. radius.

$$C = \pi D = 3.1416 \times 2 \times 2$$
$$= 3.1416 \times 4 = 12.5664 \text{ in.}$$

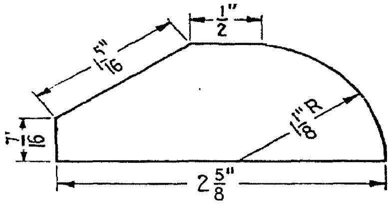


FIG. 66.

Problems:

1. Find the perimeter of Fig. 66.

2. Find the circumference of a circle with 0.75 in. diameter.

The Perimeter of an Ellipse.

An *approximate* formula for finding the perimeter of an ellipse is

$$P = \pi \sqrt{2(a^2 - b^2)} \tag{5}$$

where P = perimeter
π = 3.1416
a = $\frac{1}{2}$ major axis
b = $\frac{1}{2}$ minor axis

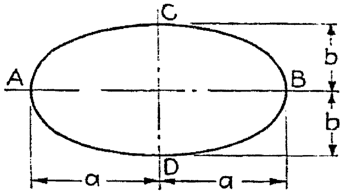


FIG. 67.—An ellipse.

Example: For an ellipse the major axis is 8 in., and the minor axis is 6 in. Find the perimeter to two places:

$$P = \pi\sqrt{2(16 + 9)}$$
$$= \pi\sqrt{50} = 3.1416 \times 7.07$$
$$P = 22.2 \text{ in.}$$

Problem: The major and minor axes of an ellipse are 18 and 14 in., respectively. Find the perimeter.

AREAS

The length of an object can be measured with a scale or micrometer, but it is impossible to measure the *area* of an object. However, by the correct use of lengths or dimensions, areas can be computed.

Since the mechanic must be able to compute the areas of certain common forms, as circles, triangles, beams, etc., the formulas for these forms will be given below.

Area is obtained by multiplying one length by another; therefore, it must be in units of square inches, square feet, square yards, etc. If measurements are made in inches, the answer will be in square inches. If measurements are made in feet, the answer will be in square feet. However, if one measurement is made in inches and the other is in feet, one measurement must be reduced to the other before multiplication can take place. That is, all measurements must be made in the same units to give the correct answer.

The Square

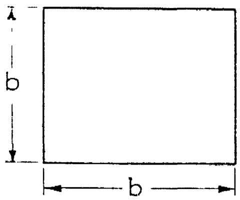


FIG. 68.—A square.

$$A = b \times b \qquad (6)$$

where A = area
b = length of side

Example: Find the area of a 6-in. square.

$$A = 6 \times 6 = 36 \text{ sq. in.}$$

The Rectangle

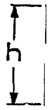


Fig. 69.—A rectangle.

$$A = b \times h \tag{7}$$

where A = area
b = base
h = altitude

Example: Find the area of a 6- by 12-in. rectangle.

$$A = 6 \times 12 = 72 \text{ sq. in.}$$

The Right Triangle

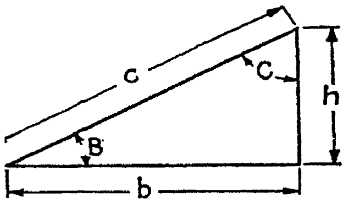


Fig. 70.—A right triangle.

$$A = \tfrac{1}{2}b \times h \tag{8}$$

where A = area
b = base
h = altitude

Example: Find the area of a right triangle with base of 8 in. and altitude of 6 in.

$$A = \tfrac{1}{2} \times 8 \times 6 = 24 \text{ sq. in.}$$

Should only the base and hypotenuse be given, the altitude can be found by the sum-of-the-square rule, as

$$C^2 = b^2 + h^2 \tag{9}$$

Should a side and an angle be given, employ trigonometry to solve for the unknown, as

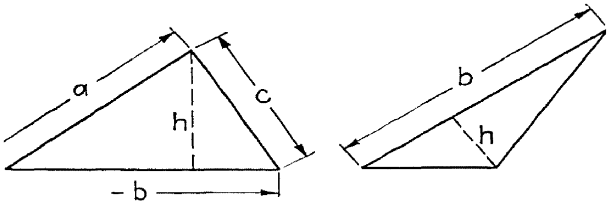
$$h = b \tan B \tag{10}$$

$$\frac{h}{\tan B} = b \tag{11}$$

Example: Find the area of a 30°-60° triangle if the side opposite the 30° angle is 6 in.

$$A = \frac{1}{2} b \times h = \frac{1}{2} h \left(\frac{h}{\tan B}\right) = \frac{6}{2}\left(\frac{6}{\tan 30}\right) = \frac{18}{.57735} = 31.2 \text{ sq. in.}$$

Oblique Triangle



(*a*) (*b*)

Fig. 71.—Oblique triangles.

$$A = \tfrac{1}{2}b \times h \tag{12}$$

where
A = area
b = base
h = altitude

Trapezoid

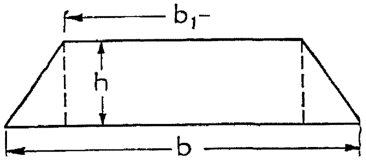


FIG. 72.—A trapezoid.

$$A = \frac{h}{2}(b_1 + b) \qquad (13)$$

where A = area
h = altitude
b_1 = top base
b = bottom base

$$\text{Area of rectangle} = b_1 \times h$$
$$\text{Area of 1 triangle} = \frac{1}{2} h \frac{(b - b_1)}{2} = \frac{1}{4} h(b - b_1)$$

But there is one triangle at each end; so total area

$$A = b_1 \times h + \tfrac{2}{4}h(b - b_1)$$

or

$$A = b_1h + \frac{bh}{2} - \frac{b_1h}{2}$$
$$A = \frac{b_1h}{2} + \frac{bh}{2} = \frac{h}{2}(b_1 + b)$$

Example: Given a trapezoid with the two bases equal to 6 in. and 8 in. and the altitude equal to 5 in. Find the area.

$$A = \frac{5}{2}(6 + 8) = \frac{5 \times 14}{2} = 7 \times 5 = 35 \text{ sq. in.}$$

Hexagon

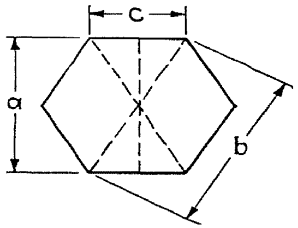


FIG. 73.—A hexagon.

$$A = \tfrac{3}{2}ac \qquad (14)$$

where A = area
a = distance across flats
c = side

NOTE:
$$a = 1.732c \qquad (15)$$
$$b = 2c \qquad (16)$$

$$\text{Area of one small triangle} = \frac{1}{2}\left(\frac{a}{2} \times \frac{c}{2}\right) =$$

But there are 12 small triangles; therefore, total area

$$A = \frac{12 \times ac}{8} = \frac{3ac}{2}$$

Example: Given a hexagon with side equal to 2 in. and distance across flats equal to 3.5 in. Find the area.

$$A = \tfrac{3}{2}(3.5 \times 2) = 3 \times 3.5 = 10.5 \text{ sq. in.}$$

Octagon (proof similar to hexagon)

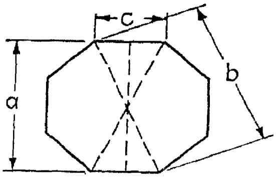


FIG. 74.—An octagon.

$$A = 2ac \tag{17}$$

where A = area
a = distance across flats
b = distance across corners
c = side

NOTE:

$$a = 2.414c \tag{18}$$
$$b = 2.613c \tag{19}$$

Circle

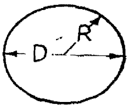


FIG. 75.

$$A = \pi R^2 = \pi D^2 \tag{20}$$

where A = area
π = 3.1416
R = radius
D = diameter

Example: Given a circle with radius equal to 2 in. Find the area.

$$A = \pi \times 2 \times 2$$
$$A = 3.1416 \times 4$$
$$A = 12.5664 \text{ sq. in.} \qquad 12.57$$

Ellipse

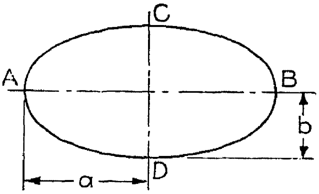


FIG. 76.

$$A = \pi ab \tag{21}$$

where A = area
π = 3.1416
a = ½ major axis
b = ½ minor axis

Example: Given an ellipse with major axis equal to 8 in. and minor axis equal to 6 in. Find the area.

$$A = \pi ab$$
$$A = \frac{\pi 8 \times 6}{4}$$
$$A = 37.699 \text{ sq. in.}$$
$$A = 37.7 \text{ sq. in.}$$

Irregular Figures.—Irregular figures usually are solved by breaking them down into combinations of the above examples, as shown in Fig. 77.

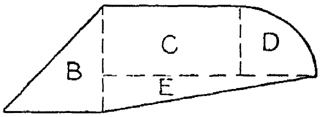


FIG. 77.

$$A = B + C + D + E$$

where A = total area
B = area of triangle
C = area of rectangle
D = $\frac{1}{4}$ area circle
E = area of triangle

Problems: Solve the following:

1. The side of a square piece of metal is 6 in. Find the area of the metal if a 2-in.-diameter hole is cut out of the center.

2. A 2- by 4-in. piece of metal is cut in 16 pieces. What is the area of each piece?

3. Find the total wing area of Fig. 78.

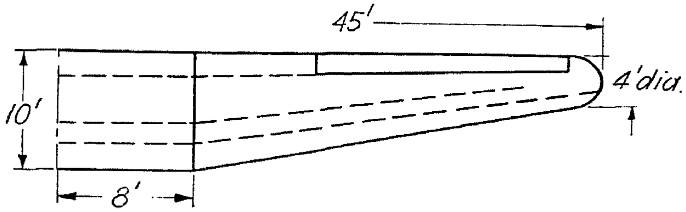


FIG. 78.

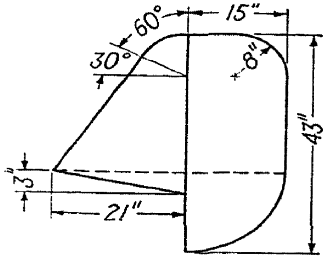


FIG. 79.

4. Find the total tail area of Fig. 79.

5. Given the dimensions for the triangle in Fig. 80. Find the area.

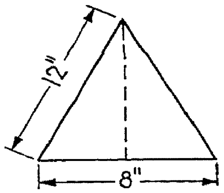


FIG. 81.

6. Given the isosceles triangle in Fig. 81. Find the area.

7. Given a hexagon with sides of 1 in. and distance across flats of 1.732 in. Find area.

8. Given a trapezoid with top base equal to 10 in., slant height equal to 10 in., and bottom base equal to 22 in. Find area.

9. If a tube has an o.d. of $1\frac{1}{2}$ in. and a wall thickness of 0.065 in., what is the area of the metal?

10. A 3- by 12-in. piece of 17ST aluminum has sixty-four $\frac{1}{8}$-in. rivet holes and forty-eight $\frac{1}{4}$-in. rivet holes. Find the area of the piece of aluminum.

11. Find the area of an ellipse whose major and minor axes are 8 and 5 in., respectively.

Volume

The volume of any object is the capacity of that object in cubic inches, feet, yards, etc.

The volume of any prism or cylinder is found by multiplying the area of the base by the altitude.

Cube

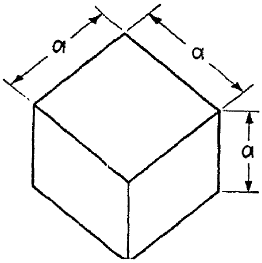


Fig. 82.—A cube.

$$V = a^3 \qquad (22)$$

where V = volume
a = length of side

Example: Given a 4-in. cube. Find the volume.

$$V = a^3 = 4 \times 4 \times 4 = 64 \text{ cu. in.}$$

Prism

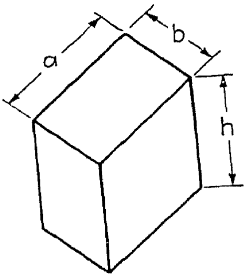


Fig. 83.—A prism.

$$V = abh \qquad (23)$$

where V = volume
a = one side of base
b = other side of base
h = altitude

If the prism has a hexagon base, octagon base or any irregular base

$$V = Ah \qquad (24)$$

where V = volume
A = area of base
h = altitude of prism

Example:

1. Given a rectangular prism whose base is 6 by 4 in. and whose altitude is 8 in. Find the volume.

$$V = abh = 6 \times 4 \times 8 = 192 \text{ cu. in.}$$

2. Given an octagon-shaped prism 6 in. high. If the sides are 4 in., find the volume.

$$V = 2ach = 2 \times 4(4 \times 2.414) \times 6 = 463.5 \text{ cu. in.}$$

Cylinder

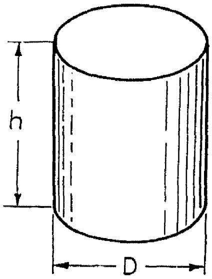


FIG. 84.—A cylinder.

$$V = \pi R^2 h = \frac{\pi D^2 h}{4} \tag{25}$$

where V = volume
R = radius
D = diameter
h = altitude
π = 3.1416

Example: Given a 6-in.-diameter cylinder 10 in. high. Find the volume.

$$V = \pi R^2 h \quad \frac{\pi D^2 h}{4} = \frac{3.1416 \times 36 \times 10}{4}$$

$$V = 31.416 \times 9 = 282.74 \text{ cu. in.}$$

Tube

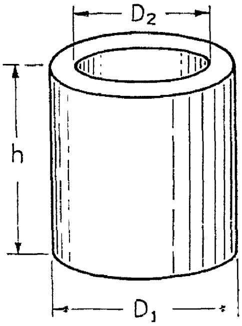


FIG. 85.—A tube.

$$V = \pi h(R_1^2 - R_2^2)$$
$$= \frac{\pi h}{4}(D_1^2 - D_2^2) \tag{26}$$

where V = volume
π = 3.1416
R_1 = outside radius
R_2 = inside radius
D_1 = o.d.
D_2 = i.d.

Example: Find the volume of metal of a 4 by ½-in. o.d. tube 10 in. long.

$$V = \frac{\pi h}{4}(D_1^2 - D_2^2) \quad \frac{3.1416 \times 10}{4}(4 \times 4 - 3.5 \times 3.5)$$

$$V = \frac{31.416}{4}(16.00 - 12.25) \quad 7.854 \times 3.75$$

$$V = 29.45 \text{ cu. in.}$$

Pyramids and Cones

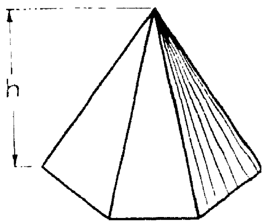


FIG. 86.—A pyramid.

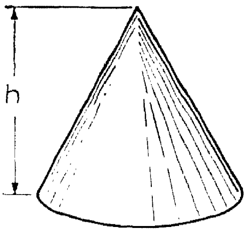


FIG. 87.—A cone.

$$V = \tfrac{1}{3}Ah \tag{27}$$

where V = volume
A = area of base
h = altitude

Example: Find the volume of a cone whose base radius is 6 in. and whose height is 12 in.

$$V = \frac{1}{3}Ah = \frac{1}{3}\frac{\pi D^2}{4}h = \frac{3.1416 \times 6 \times 6 \times 12}{12}$$

$$V = 3.1416 \times 6 \times 6 = 113 \text{ cu. in.}$$

Frustum of a Pyramid and Cone

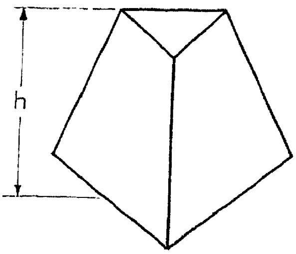


FIG. 88.

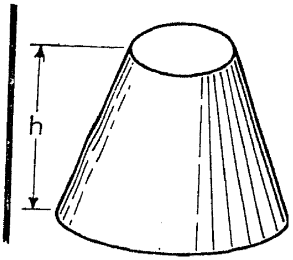


FIG. 89.

$$V = \tfrac{1}{3}h(A_1 + A_2 + \sqrt{A_1 \times A_2}) \qquad (28)$$

where V = volume
h = altitude
A_1 = area of large base
A_2 = area of smaller base

Example: Given a frustum of a cone with top radius equal to 2 in. and bottom radius to 4 in. and with height equal to 6 in.

$$V = \frac{1}{3}h(A_2 + A_2 + \sqrt{A_1 \times A_2}) = \frac{6\pi}{3}(4 + 16 + \sqrt{64})$$
$$V = 2\pi(4 + 16 + 8) = 2\pi(28)$$
$$V = 56\pi = 175.5 \text{ cu. in.}$$

Ring

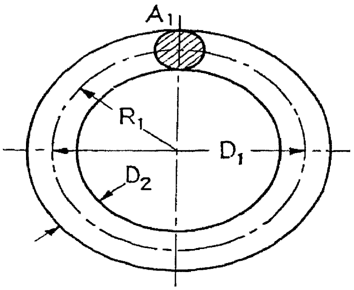


FIG. 90.

$$V = 2\pi R_1 A_1 = \pi D_1 A_1 \qquad (29)$$
$$V = 2\pi^2 R_1 R_2^2 = \frac{\pi^2}{4} D_1 D_2^2$$

where V = volume
R_1 = radius of center circle
A_1 = cross-section area = πR_2^2
D_1 = diameter of center circle
R_2 = radius of cross-section
D_2 = diameter of cross-section

Example: The o.d. of a ½-in. ring is 4½ in. Find the volume of the ring.

$$V = \frac{\pi^2}{4} D_1 D_2^2 = \frac{\pi^2}{4} \times 4 \times 0.25 = \frac{\pi^2}{4}$$
$$V = \frac{9.86}{4} = 2.47 \text{ cu. in.}$$

Sphere

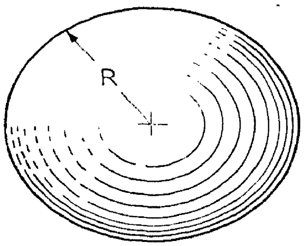


FIG. 91.

$$V = \tfrac{4}{3}\pi R^3 \qquad (30)$$

where V = volume
π = 3.1416
R = radius

Example: Find the volume of a sphere if the radius equals 4 in.

$$V = \tfrac{4}{3}\pi R^3 = \quad \times 3.1416 \times 4 \times 4 \times 4$$
$$= 256 \times 1.0472$$
$$V = 278 \text{ cu. in.}$$

1 gallon = 231 cubic inches
1 cubic foot = 1,728 cubic inches
1 cubic yard = 27 cubic feet
1 square foot = 144 square inches
1 square yard = 9 square feet

Problems: Solve the following:

1. Find the volume of a rectangular prism whose base is 8 by 6 in. and whose altitude is 14 in.

2. Find the volume of a prism 18 in. high if the distance across flats is 4 in. and the base is a hexagon.

3. Find the volume of a 20-in.-high cylinder if the diameter of the base is $3\frac{1}{2}$ in.

4. Find the volume in gallons of an elliptical gas tank 10 ft. long if the major axis is 6 ft. and the minor axis is 4 ft.

5. Find the volume of a hexagonal pyramid $9\frac{1}{2}$ in. high if the sides of the base are 5 in.

6. Find the volume of a cone 12 in. high and with a base of 8 in. diameter.

7. Find the volume of a frustum of a square pyramid 3 ft. high if the upper base is 1 ft. and the lower base is 24 in.

8. Find the volume of a frustum of a cone 2 ft. high if the top diameter is 10 in. and the bottom diameter is 18 in.

9. Find the volume in gallons of a gas tank 6 ft. long if the ends are spherical and the radius is 18 in.

10. Find the volume of a 1-in. ring if the o.d. is 6 in.

11. Find the capacity in gallons of the gas can in Fig. 92.

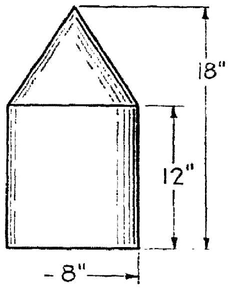


FIG. 92.

12. What will be the weight of a tube 2 in. o.d., with a 0.25-in. wall, and 24 in. long if the metal weighs 0.09 lb. per cu. in.?

LEVERS, SPEED ROTATION (GEARS AND PULLEYS)

All machines, no matter how complicated they seem, may be resolved into a combination of elementary mechanical forms. Some of these simple forms are the lever, wheel and axle, and pulley.

LEVERS

One of the most useful of simple machines is the lever. It may be defined as a mechanical device for lifting, turning, or balancing.

The simple beam balance is shown in Fig. 93. Here a long rod is balanced by placing the center of the rod on a knife-edge. Two different weights W_1 and W_2 are hung on the rod at distances

d_1 and d_2, respectively, so that the rod again is in balance. If W_1 is twice as large as W_2, d_1 will be one-half of d_2. That is,

$$W_1 \times d_1 = W_2 \times d_2 \tag{31}$$

This is called a *moment equation.*

A moment is a force times the perpendicular distance from the line of action of the force to the point about which the force acts or rotates. In Fig. 94*a* the moment is force F times distance d. In Fig. 94*b* it is necessary to extend the line of action of the force F in order to obtain the perpendicular distance d. However, the moment is still $F \times d$. Moments are measured in foot-pounds or inch-pounds.

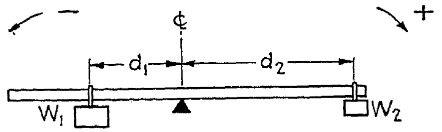


FIG. 93.—A simple beam balance.

$$\text{Moment} = F \times d \tag{32}$$

In the case of the beam balance above, the moment on the left ($W_1 \times d_1$) was equal to the moment on the right ($W_2 \times d_2$).

The sum of the moments about any point must be equal to zero to place the system in equilibrium. In order to solve moment equations it is therefore necessary to assign positive and negative values to the moments. Clockwise moments are called *positive,* and counterclockwise moments are called *negative.* With this in mind, Eq. (31) can be rewritten as follows:

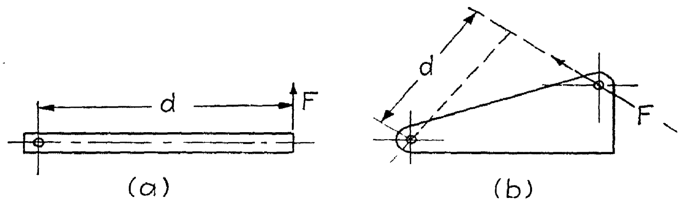


FIG. 94.—Line of action.

$$W_2d_2 - W_1d_1 = 0 \tag{33}$$

By transposition, Eq. (33) is the same as Eq. (31):

$$W_1d_1 = W_2d_2.$$

Examples:

(*a*) If W_1 (Fig. 93) is 10 lb. and W_2 is 5 lb., what must d_1 be if d_2 is 10 in.?

$$W_1 \times d_1 = W_2 \times d_2$$
$$10 \times d_1 = 5 \times 10$$
$$d_1 = \frac{5 \times \cancel{10}}{\cancel{10}} = 5 \text{ in.}$$

(*b*) If W_1 of a similar system is 25 lb. and d_1 is 48 in., what is W_2 if d_2 is 12 in.?

$$W_1 \times d_1 = W_2 \times d_2$$
$$25 \times 48 = W_2 \times 12$$
$$12W_2 = \frac{25 \times \overset{4}{\cancel{48}}}{\cancel{12}} \quad 100 \text{ lb.}$$

In many cases, the moment produces rotation, as the turning of a wheel. Such a moment is called *torque*. A good example of this is the control column of a ship. In Fig. 95 the control

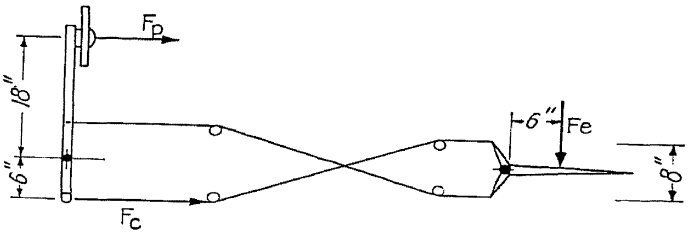


Fig. 95.

column is attached to the elevators. If in level flight a down force F_e on the elevator produces a pull F_c in the lower cable equal to 12 lb., the pilot must exert a force F_p of 4 lb. to keep the system in equilibrium. If, however, a movement of the elevator produces a pull in the bottom control cable equal to 30 lb., the pilot must exert a force equal to 10 lb. on the control column in order to produce the motion.

$$W_1 \times d_1 = W_2 \times d_2$$
$$12 \times 6 = F_p \times 18$$
$$F_p = \tfrac{72}{18} = 4 \text{ lb.}$$
$$W_1 \times d_1 = W_2 \times d_2$$
$$30 \times 6 = F_p \times 18$$
$$F_p = 10 \text{ lb.}$$

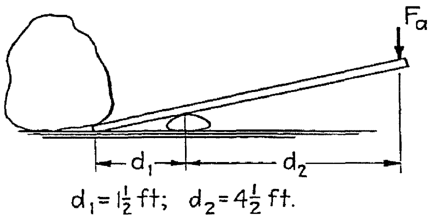


Fig. 96.

The lifting of a rock as shown in Fig. 96 is another good example of the lever.

Problems: Solve the following:

1. If force F_e (Fig. 95) were reversed (up), what would be the direction and magnitude of F_p if F_e is 40 lb.?

2. What load must a man exert to lift the 400-lb. rock of Fig. 96?

3. What is d_1 in Fig. 97 if d_2 is 72 in., P is 75 lb., and W is 200 lb.?

From Fig. 96 it can be seen that in order to lift the rock a short distance the man must move through a large distance. The farther he is from the pivot point, the greater this ratio will be.

If the force applied by the man is called the *applied force* F_a and the weight of the rock is called the *resistance* R, then the *mechanical advantage* of the machine is

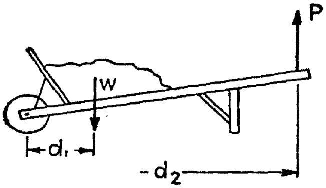


Fig. 97.

$$\text{Mechanical advantage} = \frac{R}{F_a} \qquad (34)$$

Return to the problems above, and calculate the mechanical advantage for each.

Speed Rotation

Spur Gears.—Spur gears are common gears whose teeth are perpendicular to the sides of the gears.

In a train of gears the gear driving is called the *driver*, and the other gears are called *followers*, or *driven gears*.

The speed of rotation of two meshing gears depends on the number of teeth of the gears, or upon their diameters. If the

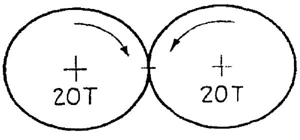


Fig. 98.—Spur gears.

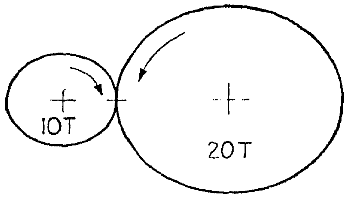


Fig. 99.

two gears shown in Fig. 98 have the same number of teeth, their speed of rotation will be the same. If the direction of rotation of the driving gear A is clockwise, the direction of rotation of the driven gear is counterclockwise. This is shown by the arrows on the wheels.

In Fig. 99, gear A has 10 teeth and gear B has 20 teeth. When gear A makes one complete revolution, the 10 teeth of A will

mesh with 10 teeth of gear B. Since B has 20 teeth, it will take two revolutions of A to give one revolution of B. This is given by the formula below:

$$T_1 \times \text{r.p.m.}_1 = T_2 \times \text{r.p.m.}_2 \tag{35}$$

or

$$\frac{T_1}{T_2} = \frac{\text{r.p.m.}_2}{\text{r.p.m.}_1}$$

where T_1 = teeth of *driving* gear
r.p.m.$_1$ = revolutions per minute of driving gear
T_2 = teeth of *driven* gear
r.p.m.$_2$ = r.p.m. of driven gear

The above states that the speeds of rotation of two gears vary inversely as their number of teeth.

Example: If gear A has 20 teeth and is turning at 300 r.p.m., what is the speed of gear B with 60 teeth?

$$\begin{array}{cc} T_1 \times \text{r.p.m.}_1 & T_2 \times \text{r.p.m.}_2 \\ \dfrac{20 \times 300}{60} & \text{r.p.m.}_2 \\ \text{r.p.m.}_2 = & 100 \text{ r.p.m.} \end{array}$$

Idler Gears.—If two gears are so far apart that it would require extremely large gears to bridge the gap, the diameters

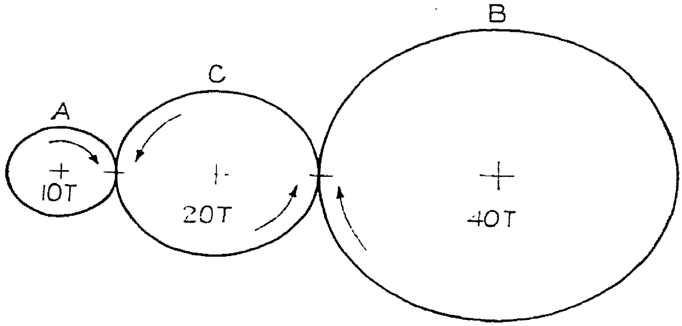


FIG. 100.—Idler gears.

of the gears are reduced and an idler gear is placed between them.

In Fig. 100, should idler gear C of 20 teeth be placed between gear A of 10 teeth and gear B of 40 teeth, the speed of C would be one-half that of A and the speed of B would be one-half that of C. That is, the speed of B is one-fourth the speed of A. However,

by computing the speeds by the formula above, it can be seen that the speed of B is one-fourth the speed of A without considering C. Therefore, the idler does not affect the speed in any way.

$$T_1 \times \text{r.p.m.}_1 = T_2 \times \text{r.p.m.}_2$$
$$\text{r.p.m.}_2 = \frac{10 \times 200}{40} = 50 \text{ r.p.m.}$$

Inspection of the figure above, however, shows that the direction of rotation of B is now the same as the direction of rotation of A. Therefore, although the idler does not affect the speed of rotation, it does change the direction of rotation.

If two idlers be placed between A and B, instead of one, the direction of rotation of B will change again and be opposite to the direction of A.

From the above statements can be formulated the following rule: If an uneven number of idlers is used, the direction of rotation of the driven gear is the same as the driver; if an even number of idlers is used, the direction of rotation of the driven gear is opposite to the direction of rotation of the driver.

Compound Gearing.—If gear A drives gear B, and gear C, keyed to the same shaft as B, drives gear D, this is called *compound gearing* (Fig. 101).

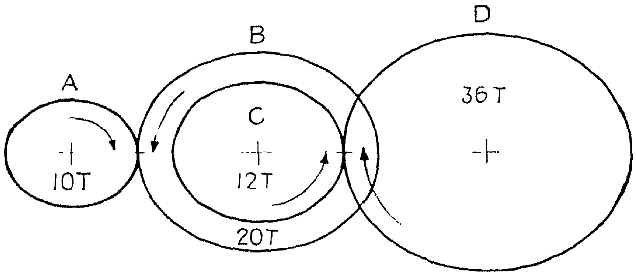


FIG. 101.—Compound gears.

From Eq. (35), if A is rotating at 600 r.p.m., then B is rotating at

$$\text{r.p.m.}_2 = \frac{600 \times 10}{20} = 300 \text{ r.p.m.}$$

Since gear C is on the same shaft as B, it must also be rotating at 300 r.p.m.; therefore, gear D will be rotating at

$$\text{r.p.m.}_4 = \frac{300 \times 12}{36} = 100 \text{ r.p.m.}$$

This can be written as an equation as follows:

$$\text{r.p.m.}_4 = \frac{\text{r.p.m.}_1 \times T_1 \times T_3}{T_2 \times T_4} \quad (36)$$

where r.p.m.$_1$ = r.p.m. of first driving gear
T_1 = teeth of first driving gear
T_3 = teeth of second driving gear
T_2 = teeth of first follower gear
T_4 = teeth of second follower gear
r.p.m.$_4$ = r.p.m. of final follower gear

In Eq. (36) all driving gears are given in the numerator, and all following gears are given in the denominator.

Beveled Gears.—Beveled gears are gears whose teeth are cut at an angle to the gear side. Problems involving beveled-gear speed ratios are solved in the same way as those for spur gears.

Worm and Worm Gears.—If the number of threads of the worm, the rotational speed of the worm, and the number of teeth of the worm gear are known, then the speed of the worm gear can be found by means of the following formula:

$$\text{r.p.m.}_{WG} = \frac{\text{r.p.m.}_W \times T_W}{T_{WG}} \quad (37)$$

where r.p.m.$_{WG}$ = r.p.m. of the worm gear
r.p.m.$_W$ = r.p.m. of the worm
T_{WG} = teeth of worm gear
T_W = threads of worm

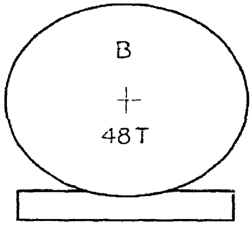


FIG. 102.—Worm gears.

If B has 48 teeth and the worm A has 3 threads and is rotating at 300 r.p.m., find the speed of the worm gear B (Fig. 102).

$$\text{r.p.m.}_{WG} = \frac{300 \times 3}{48} = 12.5 \text{ r.p.m.}$$

Pulley Trains.—Problems for pulley trains are solved like those for spur-gear trains except that the diameter of the pulleys replaces the number of teeth and the formula becomes

$$D_1 \times \text{r.p.m.}_1 = D_2 \times \text{r.p.m.}_2 \quad (38)$$

where D_1 = diameter of driving wheel
D_2 = diameter of following wheel
r.p.m._1 = r.p.m. of driving wheel
r.p.m._2 = r.p.m. of following wheel

Problems: Solve the following:

1. A gear having 88 teeth meshes with one having 22 teeth. If the large gear is making 15 r.p.m., what is the small gear making?

2. A 36-tooth gear, running at 320 r.p.m., is required to drive another gear at 240 r.p.m. How many teeth will the second gear have?

3. The speed ratio of two gears is 1 to 3. If the faster one turns at 180 r.p.m., find the speed of the slower one.

4. If the driver gear has 10 teeth and turns at 480 r.p.m., (*a*) what will be the speed of the idler gear of 20 teeth and the driven gear of 48 teeth; (*b*) what will be the direction of rotation of the driven gear if the driver turns clockwise?

5. If gear *A* of 22 teeth is driving gear *B* of 48 teeth at 480 r.p.m. and if gear *C* of 24 teeth is connected to same shaft as gear *B*, how fast will gear *C* turn gear *D* of 84 teeth?

6. What is the speed of a worm gear of 48 teeth if the worm has 3 threads and turns at 200 r.p.m.?

7. If the worm gear of Prob. 6 is on the same shaft as gear *D* of Prob. 5, how fast will the worm of Prob. 6 turn?

8. If one pulley of 10 in. diameter drives an 18-in. pulley at 400 r.p.m., how fast will the first pulley turn?

9. If gear *D* turns at 360 r.p.m., what is the speed of gear *A* (Fig. 103)?

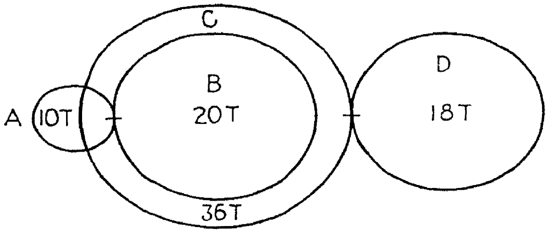


FIG. 103.

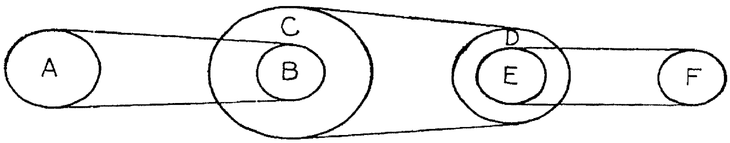


FIG. 104.

10. Find speed of *F*, if *A* = 100 r.p.m. (Fig. 104).

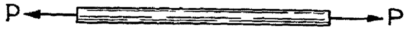
A = 10 in. diameter	*D* = 15 in. diameter
B = 5 in. diameter	*E* = 8 in. diameter
C = 20 in. diameter	*F* = 8 in. diameter

STRENGTH OF MATERIALS[1]

General Stress and Strain

An external load applied to any object tends to stretch, compress, or shear that object. This tendency to change the shape of the object is called *strain*.

The internal forces in the object resisting strain are called *stresses*. The three forms of stress are *tension*, *compression*, and *shear;* these are expressed, in terms of force per unit area, as pounds per square inch (p.s.i.).



1. Tension.—A weight hung on the end of a rod exerts a pull on the rod, or places the rod in *tension*. The stress in the rod resisting that pull is called *tensile stress* (Fig. 105).

This is expressed by the formula

$$f_t = \frac{P}{A} \tag{39}$$

where f_t = tensile stress, p.s.i.
P = total load on section, lb.
A = area of original cross-section, sq. in.

2. Compression.—A weight placed on top of a tube tends to compress or crush the tube, placing it in *compression*. The stress developed in the tube to resist the external force is called *compressive stress* (Fig. 106).

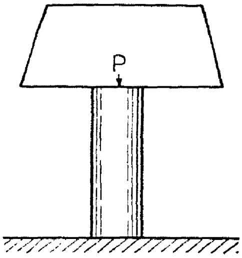


Fig. 106.—Compression.

This is expressed by the formula

$$f_c = \frac{P}{A} \tag{40}$$

where f_c = compressive stress, p.s.i.
P = total load, lb.
A = area of original cross-section, sq. in.

3. Shear.—When two sheets of metal, held together by a rivet, are subjected to a load as in Fig. 107*a*, the force exerted on the rivet, tending to cut it in two, is called a *shearing force*.

[1] Most of the formulas in this section are from the ANC-5 "Strength of Aircraft Elements."

The stress in the rivet resisting the cutting action is called *shear stress.*

If the rivet joint can be broken by shearing the rivet in one place only, as in Fig. 107*a*, the rivet is in single shear. If the rivet must be cut twice to break the joint, the rivet is in double shear. The joint in double shear will carry twice the load a joint in single shear will carry.

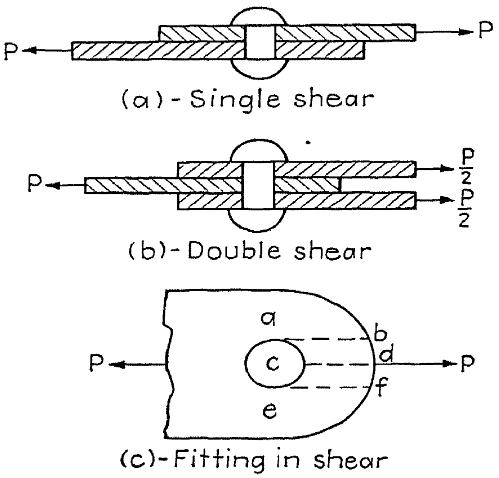


FIG. 107.

Another form of shear is the action that takes place between a bolt and the end of a fitting, tending to pull the end of the fitting out. This shear takes place along lines *ab* and *ef*, Fig. 107*c*. However, since distance *ab* is difficult to measure, 2 times distance *cd* is used to compute the shear area. This is permissible, for 2*cd* is less than *ab* + *ef*.

The above is expressed by the formula

$$f_s = \frac{S}{A \times n} \tag{41}$$

where f_s = shear stress, p.s.i.
S = total shear force, lb.
A = area of cross-section, sq. in.
n = number of sections being sheared

4. Elastic Deformation.—When loads are applied to a body, the form of the body is changed. If, when these loads are removed, the body returns to its original form, the change in form of the body above is called *elastic deformation.*

5. Permanent Deformation.—When the loads of the elastic deformation are increased to such an extent that the body fails to regain its original form upon removal of the loads, the deformation is called a *permanent deformation* or *permanent set.*

6. Elastic Limits.—The elastic limit is the greatest load per square inch of original cross-sectional area that a material can withstand without a permanent deformation.

7. Ultimate Strength.—The highest load required to break an object divided by the original cross-sectional area is the ultimate strength of that object.

8. Bearing.—The clevis pin (Fig. 108) is being forced against the end of the link; *i.e.*, the pin is *bearing* against the side of the hole. The force exerted by the bolt against the link that

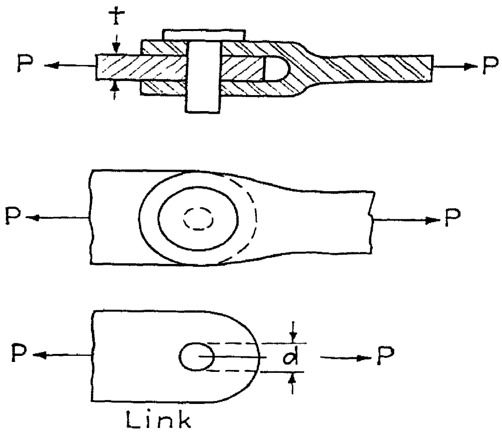


FIG. 108.—Bearing.

tends to crumple or elongate the hole in the link is called *bearing force*. The internal resisting force is *bearing stress*.

$$f_{br} = \frac{P}{A} \tag{42}$$

where f_{br} = bearing stress, p.s.i.
P = total load, lb.
A = projected area of cross-section, in sq. in.

or

$$A = t \times D$$

where t = thickness of material
D = diameter of hole

9. Ultimate Stress.—When ultimate stresses replace stress in the above formulas,

F_{tu} = ultimate tensile stress
F_{cu} = ultimate compression stress
F_{su} = ultimate shear stress
F_{br} = ultimate bearing stress

These symbols replace f_t, f_c, f_s, and f_{br} in the foregoing formulas.

10. Margin of Safety—Safety Factor.—Because of change in loads with varying flight conditions, the CAA has specified special *load factors* as well as a *factor of safety* to be used in the design of all structures. The *design load* then becomes the actual load multiplied by the load factor and the factor of safety. The load factor varies with each condition, but the safety factor is 1.5 for most conditions.

$$P_D = P \times n \times j \tag{43}$$

where P_D = design load, lb.
P = applied total load, lb.
n = load factor, no units
j = safety factor, no units

In order to determine whether or not a member is satisfactory, a comparison is made between the ultimate load a member will withstand and the design load required. This is called *margin of safety* (M.S.) and is expressed as follows:

$$\text{M.S.} = \frac{\text{ultimate load}}{\text{design load}} - 1 \tag{44}$$

$$\text{M.S.} = \frac{\text{ultimate unit stress}}{\text{design-load unit stress}} - 1 = \frac{F}{P} - 1 \tag{45}$$

CHAPTER III

THEORY OF FLIGHT AND DESIGN

THEORY OF FLIGHT

General

The purpose of this chapter is to give the student the general knowledge of all forces acting on the airplane that he needs in order that he may intelligently repair, rig, and balance any plane. At the end of this chapter is a group of definitions that he should study before proceeding with this chapter.

Air

Just as water supports boats, air supports airplanes. Much of the theory used in the design of ships is applicable to the design of airplanes. The biggest difference between air and water is that air is compressible (however, it is considered noncompressible in the development of theory) but water is not and that the density of air is much less than the density of water. That is, the weight per cubic foot is less for air than for water.

The air ocean completely surrounds the earth's surface, extending upward to an altitude of 25 miles. Standard atmospheric pressure varies from 29.92 in. of mercury (14.7 p.s.i.) and 59°F. at sea level to 7.37 in. of mercury and −67°F. at 34,000 ft. That is, the atmosphere at 59°F. will exert sufficient pressure to support a column of mercury 29.92 in. high. Change in pressure and temperature for change in altitude is given in Fig. 109.

The change in pressure with altitude is due to the change in the column of air, as when a diver descends in water. The lower the diver goes, the greater becomes the pressure owing to the increasing weight of the volume of water above him.

Since the temperature of the air is due largely to the radiation of the sun's rays from the earth, it will vary inversely as the distance from the earth, *i.e.*, 3°F. for every 1,000 ft.

Temperature and pressure also vary greatly from one locality to another, owing to changes in terrain. These changes

cause high- and low-pressure areas, and this gives the air movement.

Air closest to the earth is the hottest; yet hot air is lighter than cold air. Therefore, the air closest to the earth will rise. As the hot air rises, cold air rushes in below. The rising air cools as it rises, and so the cycle continues. At the same time, the hot air near the earth is absorbing moisture from the rivers, lakes, etc.

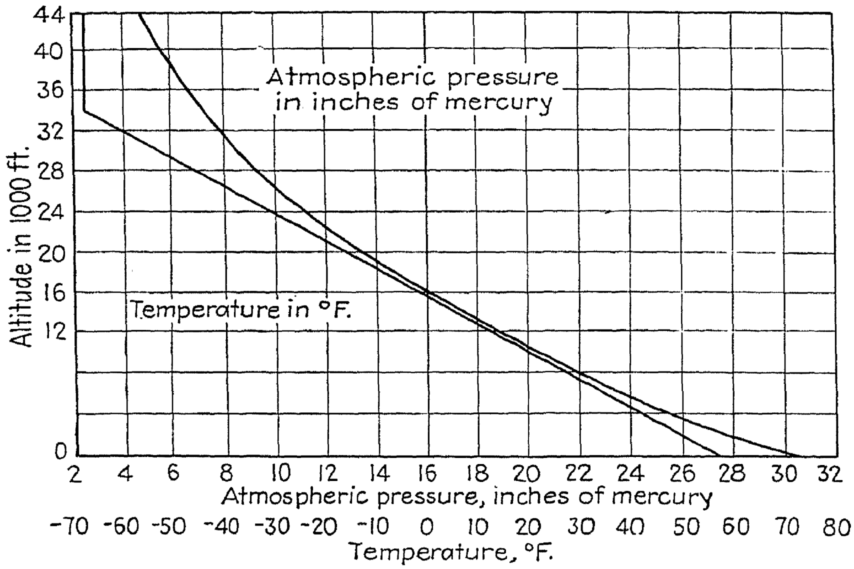


FIG. 109.—Variations in temperature and pressure with changes in altitude.

Since hot air will hold more moisture than cold air, the moisture will condense as the hot air rises, causing rains, snows, etc.

Because hot air will absorb more moisture than cold air and yet is lighter, it can be seen that moist air is lighter than dry air.

The density of air is expressed by the Greek letter rho (ρ); thus,

$$\rho = \frac{1}{g} \times \frac{\text{weight, lb.}}{\text{cu. ft.}} \tag{46}$$

where ρ = density of air, slugs per cu. ft.

g = acceleration of gravity (32.2 ft./sec./sec.)

Standard air density at sea level is 0.002378 slug per cu. ft. Since atmospheric pressure varies with altitude, air density will also vary with altitude in the same proportions.

Flight Forces

Figure 110 shows the four main forces acting on an airplane in *level* flight at a constant speed. The weight, or the force of gravity, is equal but opposite to lift. Thrust, furnished by the propeller, is equal but opposite to drag. Should any of these forces change, either the altitude or the speed of the ship must change.

As the weight becomes less owing to fuel consumption, the ship tends to rise. By increasing the lift the ship rises, and by decreasing the lift the ship descends. When the thrust is increased, the ship accelerates until the drag equals the new thrust. Should the thrust be decreased, the ship will slow down until the drag again equals the new thrust. Should the drag be increased by means of flaps or change in angle of attack, the opposite holds true.

Lift.—The air is assumed to lie in small layers extending upward from the surface of the earth. These layers are closer

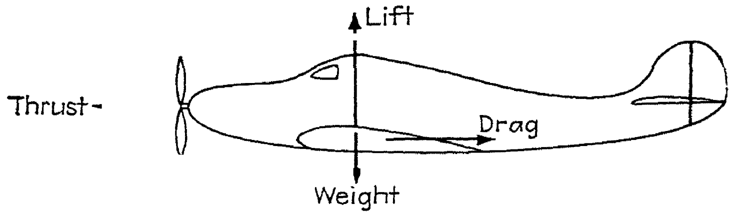


Fig. 110.—Forces acting on a plane in level flight.

together near the earth because the density of the air is greater. It is assumed that the air is constantly moving and that any particle of air creates a small line as it moves, called a *streamline*. Since the result is the same whether the air moves by the plane or the plane moves in the air, the assumption above may be made. If the particle moves at a constant rate of speed in a straight line, the air is called *smooth air*. If this particle moves in many directions at many different speeds, the air is called *turbulent air*. These streamlines for smooth air are assumed to be parallel to the earth, at a given distance apart, and moving at a constant rate of speed. Air is also considered noncompressible. Any group of these lines will be called an *air channel* (see Fig. 111*b*).

In Fig. 111*d*, an airfoil has been inserted in the streamlines of Fig. 111*b*. The air is now passing over and under the section. Since as was stated above air is assumed to be noncompressible,

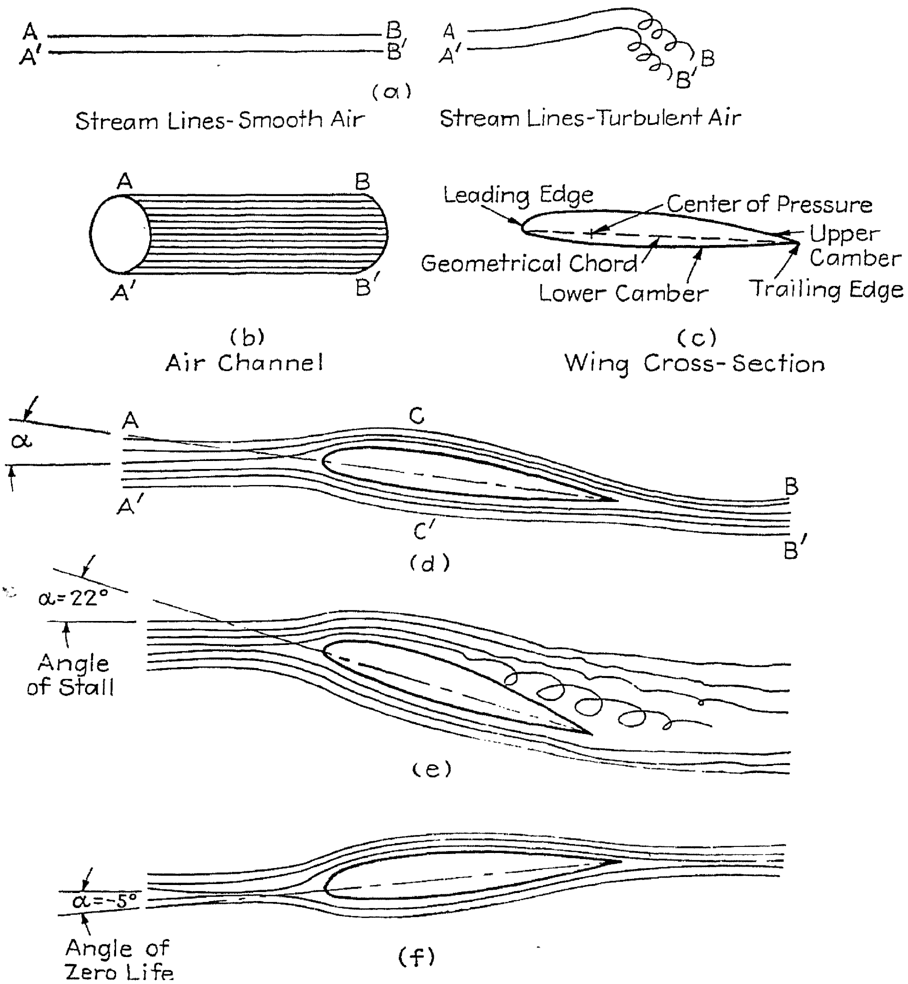


FIG. 111.—Air streams, air channel, and airflow around a standard wing section at various angles of attack.

a cross-section of the air channel passing AA' in front of the airfoil at a given time must also pass BB' at the same time. The air passing over the top of the wing must travel faster than the air passing under the wing because the distance across the top of the wing is greater than the distance across the bottom of the wing.

From Bernoulli's physical equation it can be stated that, in an air channel like the one above, pressure times velocity must equal a constant, and the following equation can be written:

$$P_A \times V_A = P_B \times V_B = P_C \times V_C = P_{C'} \times V_{C'} = C \quad (47)$$

where P_A = pressure at cross-section A, lb. per sq. ft.
V_A = velocity at cross-section A, ft./sec. (f.p.s.)
P_B = pressure at cross-section B, lb. per sq. ft.
V_B = velocity at cross-section B, f.p.s.
P_C = pressure at cross-section C, lb. per sq. ft.
V_C = velocity at cross-section C, f.p.s.
$P_{C'}$ = pressure at cross-section C', lb. per sq. ft.
$V_{C'}$ = velocity at cross-section C', f.p.s.
C = constant

From Eq. (47), the velocity on top of the wing, or at point C, is greater than the velocity on the bottom of the wing, or at point C'. Therefore, from Bernoulli's equation the pressure on top of the wing, *at any location*, will be less than the pressure on the bottom of the wing, at the same location. This decrease in pressure on top of the wing causes the wing to rise.

The angle that the geometrical chord line makes with the streamlines is called the *angle of attack* of the wing. This angle is expressed by the Greek letter alpha (α) and is shown in Fig. 111*d*. As the angle of attack is increased, the velocity across the top of the wing will increase, giving an increase in lift. This increase in lift will continue until an angle of attack of 15 to 22° is reached. At this point, the air flow over the top of the wing breaks down and the lift falls off sharply, owing to the "burbling," or breaking away of the air. This angle of attack is called the *angle of stall* (Fig. 111*e*). As the angle of attack is decreased, the lift will decrease until the streamline distance across the top of the wing will equal the streamline distance across the bottom of the wing, as shown in Fig. 111*f*. At this point, there will be no lift, and the angle of attack is called the *angle of zero lift*.

The lift is considered concentrated at a point called the *center of pressure* (c.p.). This is shown in Fig. 111*c*. As the angle of attack increases, the c.p. moves forward; as the angle of attack decreases, it moves rearward. On a stable wing section this travel is very small, but on unstable sections it varies con-

siderably. Just before the plane reaches the angle of stall, the lift reaches its maximum value; just after the angle of stall, it falls off considerably. Before the airplane reaches the angle of stall, because of the increase of lift it will fly at its lowest speed. This speed is the landing speed of the plane. After it has reached its stalling point, there is no longer enough lift to support the plane, and it will fall rapidly toward the ground until the speed is sufficient to maintain level flight again. The

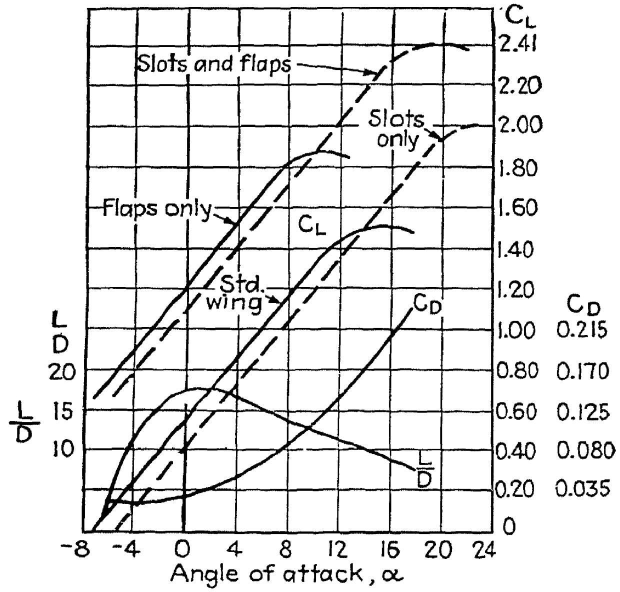


FIG. 112.—Airfoil characteristics for an average wing section.

change of lift with the angle of attack is expressed in coefficient form to make it applicable to any wing using the same airfoil. Lift varies considerably with different airfoil sections but is always the same with the same airfoil section under the same conditions. Angle of attack α versus the lift coefficient C_L for an average airfoil is given in Fig. 112. Lift for any airfoil can be figured by the following equation if the lift curve, wing area, and plane weight are known:

$$L = W = \tfrac{1}{2}\rho S V^2 C_L \tag{48}$$

where L = lift, lb.
W = weight of airplane, lb.
ρ = density of air at the altitude

V = velocity, f.p.s.
S = wing area, sq. ft.
C_L = lift coefficient for the given angle of attack at which the airplane is flying

The above analysis of lift is not complete but is sufficient for this text.

Drag.—Drag comes from two main sources, the wing and the plane.

1. Wing drag is divided into two parts, profile drag and induced drag. Profile drag is due to the shape of the wing and remains fairly constant for change in angle of attack. Induced drag comes from bending of the air around the airfoil for changes in angle of attack.

An average curve of wing drag versus angle of attack is given in Figure 112; the drag coefficient is expressed without units. From this curve it can be seen that drag increases with the angle of attack. When the angle of stall is reached, the lift falls off sharply but the drag increases rapidly. The breaking down of the air flow that gave the decrease of lift is responsible for this sharp rise in drag. When the angle of attack is decreased below zero, the drag falls off for a short while and then increases again.

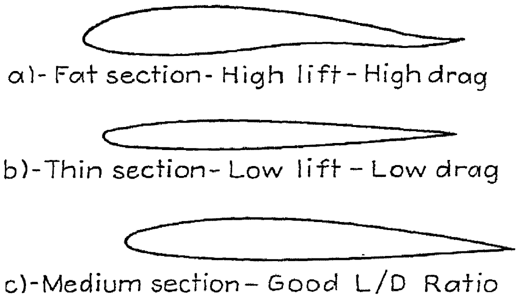


FIG. 113.—Typical airfoil sections.

The lift-drag combination depends entirely on the wing section, each section having its own peculiarities. The thin racing wing has very little drag but also little lift. The fat sections have high lift with high drag (Fig. 113). The modern wing section tries to obtain maximum lift with minimum drag.

Wing drag is expressed by the equation

$$D = \tfrac{1}{2}\rho S V^2 C_D \tag{49}$$

where D = drag, lb.
ρ = density of air
S = wing area, sq. ft.
V = velocity, f.p.s. (m.p.h. $\times$ 1.47 = f.p.s.)
C_D = drag coefficient (no units)

2. Fuselage drag is called *parasite drag* because it renders no service but is a parasite to performance. It is due to fuselage shape, landing gear, wires, etc. Parasite drag increases only a small amount with increase in angle of attack.

It can be seen from Eqs. (48) and 49 that both lift and drag depend on the density of air and velocity for the same plane and the same angle of attack. Also, it can be seen from these equations that, for the same lift coefficient, the airplane must fly faster at higher altitudes to maintain level flight because of the decrease in density.

Thrust.—The forward motion of the plane and, therefore, the lift are furnished by the thrust. Heat energy converted into

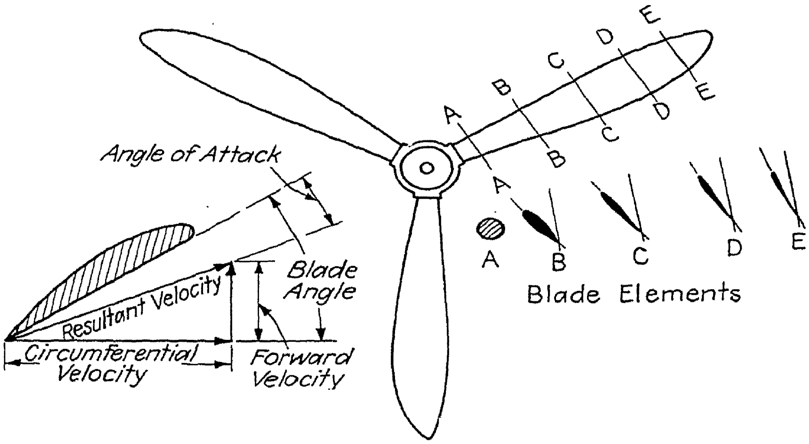


Fig. 114.—Propeller, blade sections, and blade elements. The blade-element velocities increase with an increase in the distance from the hub. Since lift or thrust increases with an increase in velocity, the blade angle decreases as this distance is increased.

mechanical energy in the engine turns the propeller. As the propeller turns, a pull, or thrust, is exerted. The propeller consists of two or three blades fastened together at the center by a hub. The cross-section of the blades is the same as the cross-section of a wing. Therefore, the propeller is nothing more than two or three wings rotating in the air (Fig. 114). The relationship between the angle of attack and the blade angle is shown in Fig. 114. The blade angle is greatest close to the hub of the propeller and gradually decreases toward the tip.

While the propeller is being turned by the engine, it is biting into the air. This action may be compared to that of a screw

being driven into wood. The lift resulting from the turning of the blades is called *thrust* and gives a forward motion to a definite distance, depending on the blade angle and the diameter. If the propeller were turning in a solid, like the screw in the wood, it would pull without slipping, and so the distance traveled in one revolution would equal the theoretical travel of the propeller. Since the propeller is turning in air, however, there is some slip and the actual travel of the propeller is less than the theoretical travel. The slip may be compared to what happens when a wheel of a car is turning in the sand. While the car is pulling on a hard surface, there is positive action; when the car runs off the road into sand, the wheels spin much faster in the sand to give the same pull as was delivered on the road. This is because the sand is not solid. Since, in aeronautics, the air is considered a liquid, and not a dense one, the same thing holds true for the propeller giving slip. Slip may be called loss of thrust, and the efficiency of the propeller depends on the amount of slip. Present-day propellers are quite efficient, however, running 85 per cent.

Horsepower required for flight is obtained by the equation below:

$$\text{Hp.}_r = \frac{DV}{550} \tag{50}$$

where Hp. = horsepower required
D = total drag of plane, lb.
V = velocity, f.p.s.

As has been pointed out, there must be an increase in velocity at altitude to compensate for decrease in air density. However, from Eq. (50) it can be seen that, with an increased velocity, the horsepower must increase, because drag remains constant. Yet, with an increase in altitude, horsepower decreases. To overcome this loss of power with decrease in air density, supercharged engines were manufactured. This gives greater horsepower up to the critical altitude of the engine.

Axis

An airplane is assumed to move, or rotate, about three conveniently chosen axes, perpendicular to each other, intersecting at the center of gravity (c.g.) of the airplane, and the airplane is

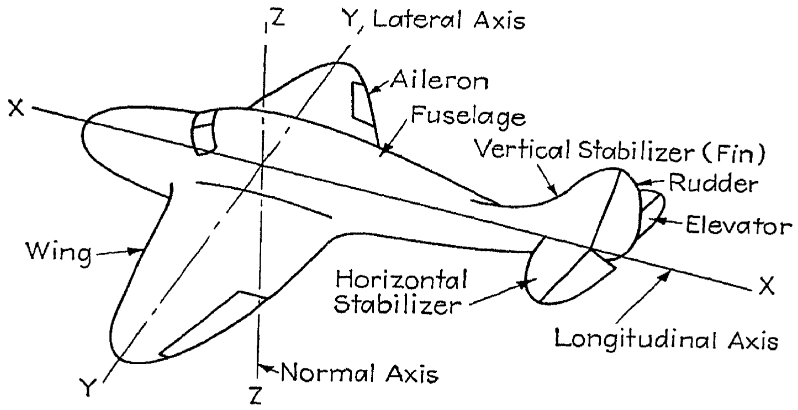


FIG. 115.—Three conventional axes.

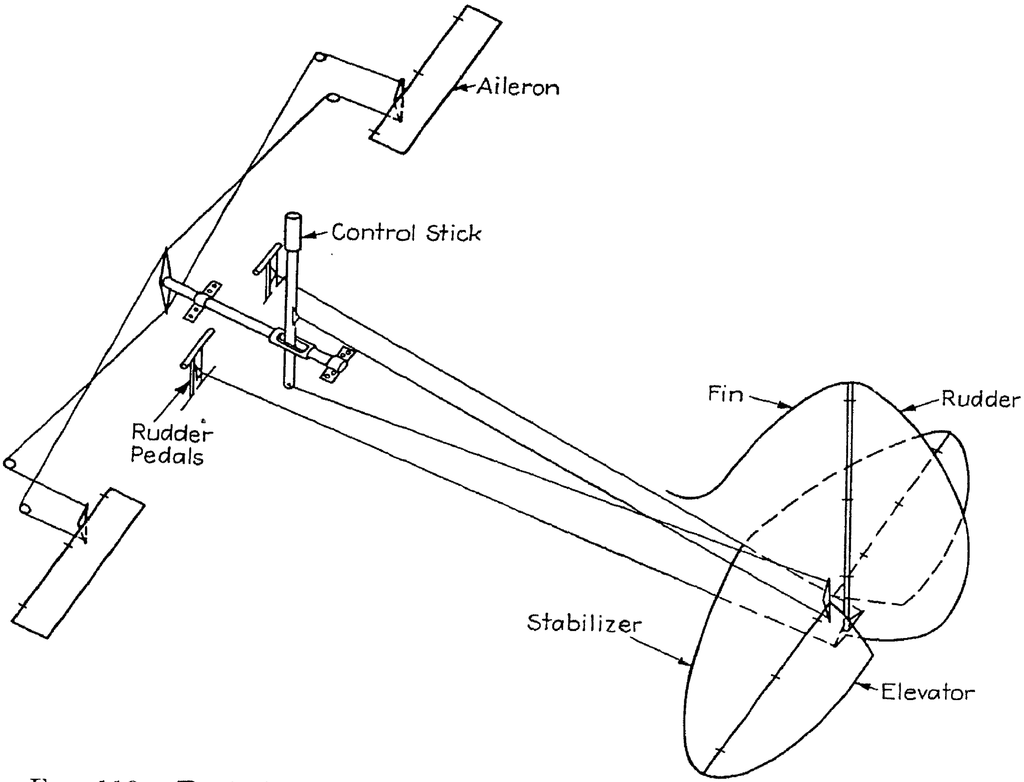


FIG. 116.—Typical control system. Pushing the control stick forward or backward operates the elevators. Moving it from right to left operates the ailerons. Pushing the right rudder pedal moves the rudder to the right, and pushing the left rudder pedal moves the rudder to the left. All controls must be operated together for smooth flying.

assumed to be suspended in air from the c.g. location (see Fig. 115).

The lateral axis, or Y axis, runs laterally through the airplane and is the axis about which the plane pitches, or moves up or down. The longitudinal axis, or X axis, runs longitudinally through the airplane and is the axis about which the plane rolls. The normal axis, or Z axis, runs vertically through the plane and is the axis about which the plane yaws, or turns right or left. An airplane is designed for *stability*, *control*, and *balance* about these three axes.

Figure 115 shows the ship and the axes about which it rotates. Figure 116 shows the control system of a standard airplane.

1. Stability is the ability of the airplane to return to its original flight path should it be disturbed from this path by an outside air force. Stability is built into the plane by the manufacturer and designer.

STABILITY

Type of stability	About axis	Plane stable in	Component giving stability
Longitudinal	Lateral (YY)	Pitch	Horizontal stabilizer
Lateral*	Longitudinal (XX)	Roll	Dihedral wing
Directional	Normal (ZZ)	Yaw	Vertical stabilizer

2. Control is the ability of the pilot to overcome the stability of the plane by use of the controls to obtain any desired attitude.

CONTROL

Type of control	About axis	Plane action	Component moving to give control
Longitudinal	Lateral (YY)	Pitch	Elevators
Lateral	Longitudin l (XX)	Roll	Ailerons
Directional	Normal (ZZ)	Yaw	Rudder

3. Balance is the ability of an airplane to fly continually at various altitudes for different loading (air and weight) conditions without requiring a constant pressure upon the controls by the pilot. Balance may also be improved by proper loading of the ship by the line crew.

BALANCE

Type of control	About axis	Plane movement	Component adjusted by
Longitudinal	Lateral (*YY*)	Pitch	Adjustable horizontal stabilizer or elevator tab
Lateral	Longitudinal (*XX*)	Roll	Washin or washout wing tip, or tab
Directional	Normal (*ZZ*)	Yaw	Adjustable vertical stabilizer, or rudder tab

4. Dihedral.—When an airplane in level flight drops a wing, that wing will remain down until the lift on the low wing is

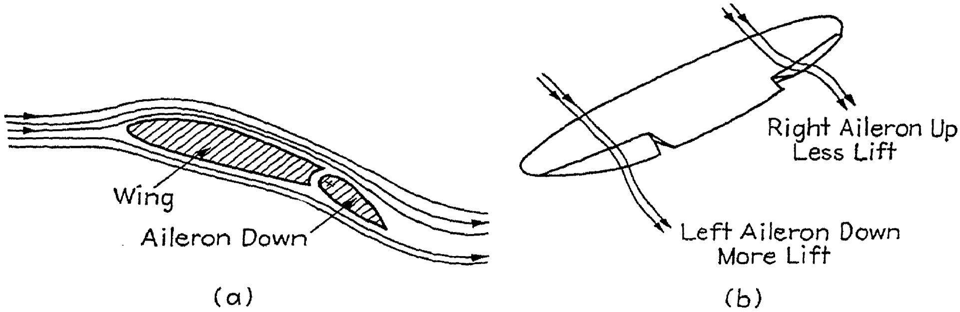


FIG. 117.—Aileron and air flow.

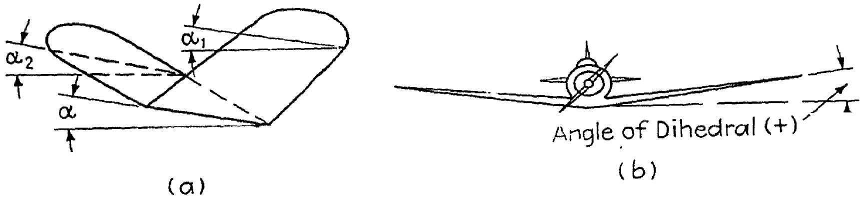


FIG. 118.—Sketch showing dihedral, and how the angle of attack increases on the low wing to give more lift.

increased and the lift on the high wing is decreased. This may be accomplished by means of the ailerons or with dihedral. In Fig. 117*a* the trailing edge of the wing has been cut and lowered as would be the case when an aileron is lowered. This increases the effective angle of attack of the wing, giving it greater lift. At the same time the aileron on the other wing will rise, decreasing its angle of attack and thus decreasing its lift (Fig. 117*b*). This righting of the ship is done by *control*.

In the case of dihedral the lower wing has a greater angle of attack than the higher wing, owing to the dihedral angle (Fig. 118*b*). This is very difficult to show by means of projection but does hold true (Fig. 118*a*). Should the dihedral angle be too small, the correction would be slow and inadequate. Should the dihedral angle be too great, the correction will be violent, creating an increasing rolling action. This means of righting the ship is a design characteristic for stability.

5. Longitudinal Balance.—Figure 119 shows an airplane with all the major forces acting on it in level flight, at a constant speed, in a given direction. This includes a tail force not previously given (see Fig. 119).

where L = lift, lb.
T = thrust, lb.
D = drag, lb.
W = weight, lb.
F_t = tail force.
a = arm, ft.
b = arm, ft.
l = arm, ft.

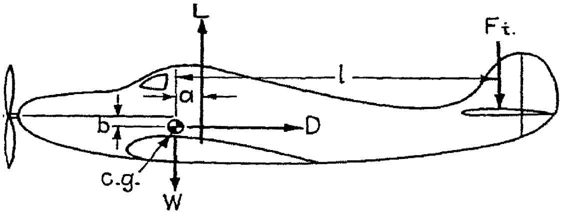


FIG. 119.—Balance diagram for level flight.

In order for the ship to remain in level flight, at a constant speed, and in a given direction, the summation of the fore and aft forces, the up and down forces, and the moments about the c.g. must be equal to zero. Assuming that the up forces and the forces to the right are plus, the down forces and the forces to the left minus, the clockwise moments plus, and the counterclockwise minus, the following equations can be written:

$$+L - F_t - w = 0 \tag{51}$$

$$+D - T = 0 \tag{52}$$

$$l \times F_t - a \times L - b \times T + D \times 0 + W \times 0 = 0 \tag{53}$$

and

$$F_t = \frac{aL + bT}{l}$$

With the c.g. location in front of the center of lift there must be a down force on the tail to balance the airplane. This is accomplished by moving the leading edge of the horizontal stabilizer down and thus increasing the distance of the air flow across the bottom of the stabilizer, giving lift in a down direction (see Fig. 120).

Should the c.g. of the ship be moved rearward by shifting the load location, there must be an up load on the tail to balance the moments about the c.g. This may be accomplished by moving the leading edge of the horizontal stabilizer up and thus increasing

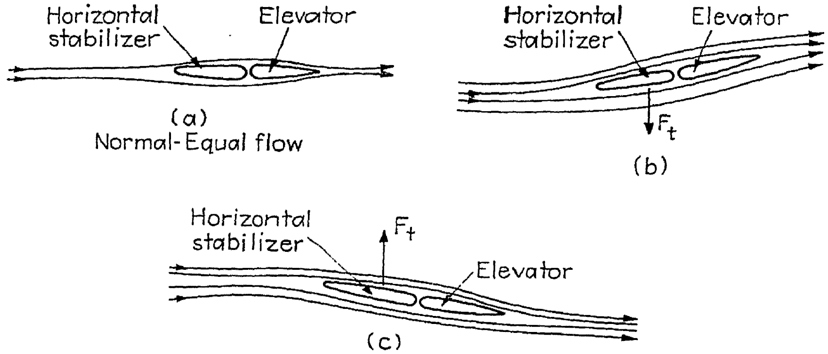


Fig. 120.—Adjustable horizontal stabilizer and elevator showing air flow.

the air-flow distance across the top of the stabilizer, giving lift in the upward direction.

In order to place the ship in a climbing position after take-off, it is necessary to place a down force on the tail. This may be accomplished as above by moving the horizontal stabilizer down.

In order to place the nose of the ship below the horizon as for descent, it is necessary to place an up load on the tail. This

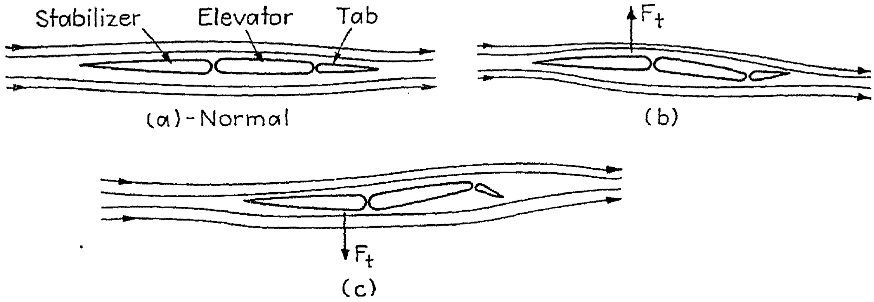


Fig. 121.—Fixed horizontal stabilizer and elevator with adjustable twin tab, showing air flow.

may be accomplished as above by moving the leading edge of the horizontal stabilizer up.

Should the stabilizer be fixed, the above loads must be attained by means of fixed or adjustable tabs on the elevators. Fixed

tabs are adjustable only by the mechanic on the ground. Adjustable tabs may be adjusted by the pilot in the air to compensate for change in loads.

The tab is a small, movable or fixed surface attached to the trailing edge of the elevator. When the tab is moved down, the elevator moves up and a down force is placed on the tail. Should the tab be moved up, the elevator will move down and an up load is placed on the tail (see Figs. 121*a*, *b*, and *c* and 122).

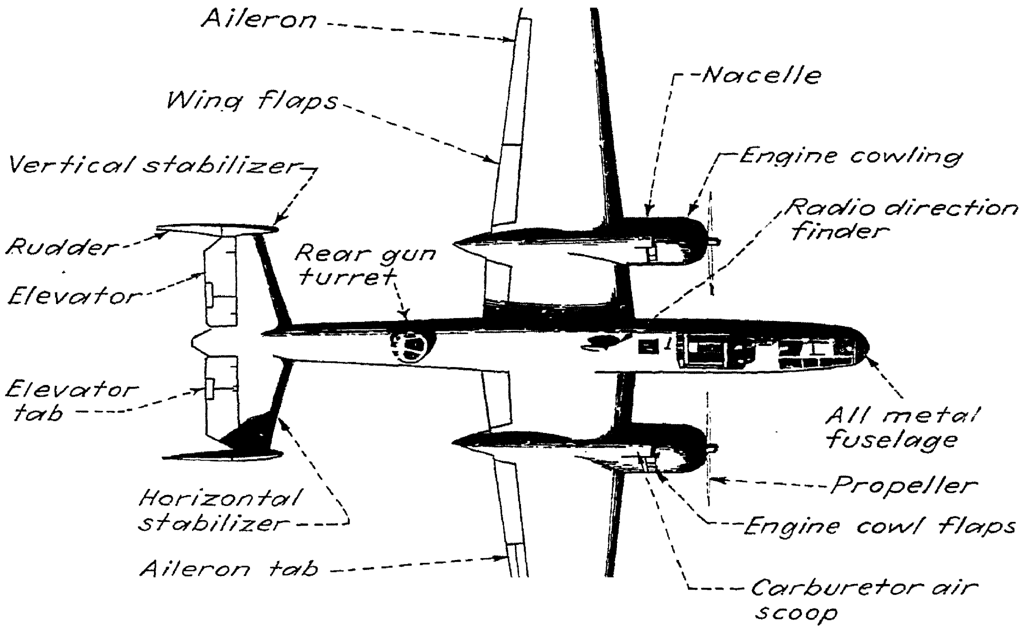


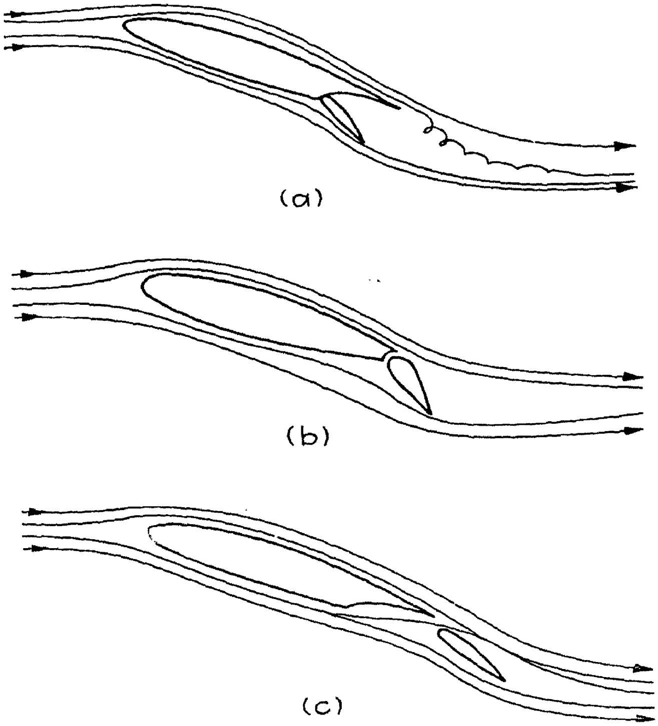
FIG. 122.—Army North American B-25 twin-engine bomber, with components named. This ship has a tapered high wing.

A typical tail group (called *empennage*) is shown in Fig. 139. This installation employs fixed stabilizers and adjustable tabs.

6. Lateral Balance.—Lateral unbalance is due to a wing-heavy condition, such as left wing heaviness, caused by torque. This is corrected on ships whose wings are supported by flying wires, or struts, by warping down the trailing edge of that wing tip (called *washin*). This increases the effective angle of attack, giving greater lift to the low wing. Washin may be accom-

plished only on the ground by the mechanic by shortening the rear flying wires, or struts. Care must be taken not to induce extreme loads in the remaining wires, or struts. On fixed cantilever wings washin is achieved by fixed tabs at the trailing edge of the wing.

Since neither of the above methods permits the pilot to correct for change in air loads in the air, all expensive airplanes today



(*a*) *Split Trailing Edge*
High lift
High drag
Poor air flow
Bad recovery from stall
Easy to manufacture
(See Fig. 124)

(*b*) *Full Trailing Edge*
High lift
Less drag than (*a*)
Better air flow than (*a*)
Move difficult to manufacture than (*a*)
(See Fig. 125)

(*c*) *Fowler Flap*
Highest lift by increase in wing area as well as angle of attack
Medium drag
Better flow
Better recovery
Very difficult to manufacture
(See Fig. 126)

FIG. 123.—Three types of wing flaps.

have adjustable tabs on the ailerons. Here the theory is the same as for horizontal stabilizers.

7. Directional Balance.—Directional unbalance is due to the ship's always tending to turn either to the right or to the left, requiring opposite rudder by the pilot. This is corrected by moving the leading edge of the vertical stabilizer (fin) in the direction of unstability (see Fig. 122). For example, if a ship tends to turn to the left owing to torque, the leading edge of the vertical stabilizer would be moved to the left. The theory employed for the horizontal stabilizer applies here, also. This

movement is possible only on the ground. For ships with fixed fins the above may be accomplished by means of a fixed

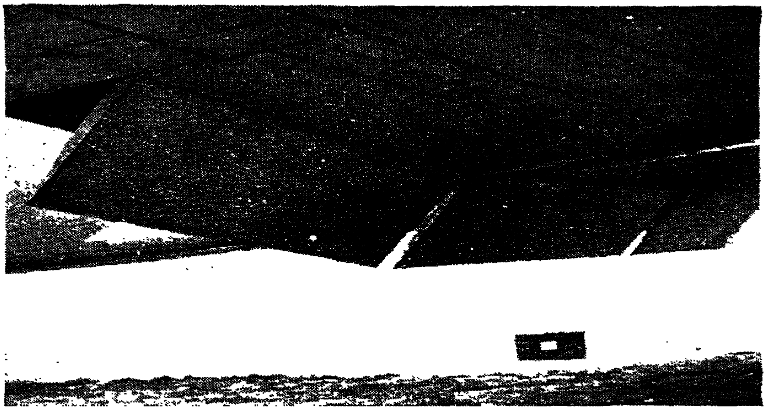


FIG. 124.—Split-trailing-edge flap of a Douglas DC-3 in the full down position viewed from the front and side.

or adjustable tab. Again the theory employed for the elevator-tab combination applies.

High Lift Devices

1. Flaps.—The designer continually looks for means to obtain greater lift. This may be accomplished with flaps, but by

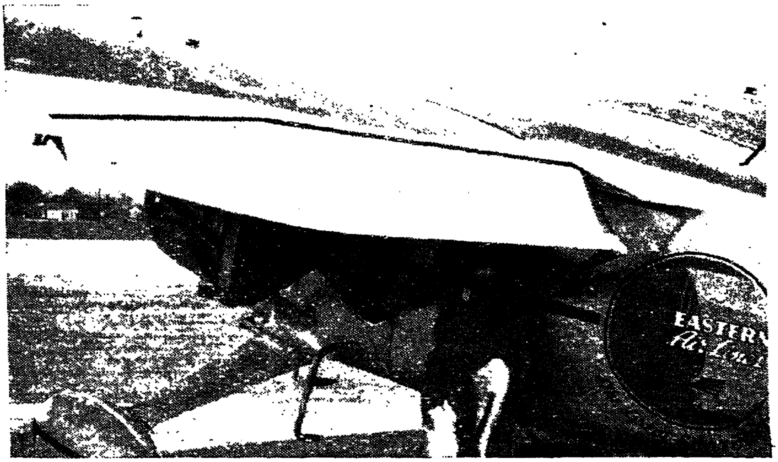


FIG. 125.—Full-trailing-edge flap on a Stinson in the down position. (*Courtesy of Eastern Air Lines, Inc.*)

paying the price of greater drag. Since the use of flaps gives greater drag, they are practical to the fullest extent only for land-

ings when high lift and drag are desired. For short take-off distances, flap travel is limited to only 10° on split trailing-edge flap and to 15° on full trailing-edge flap. Flaps work on the same

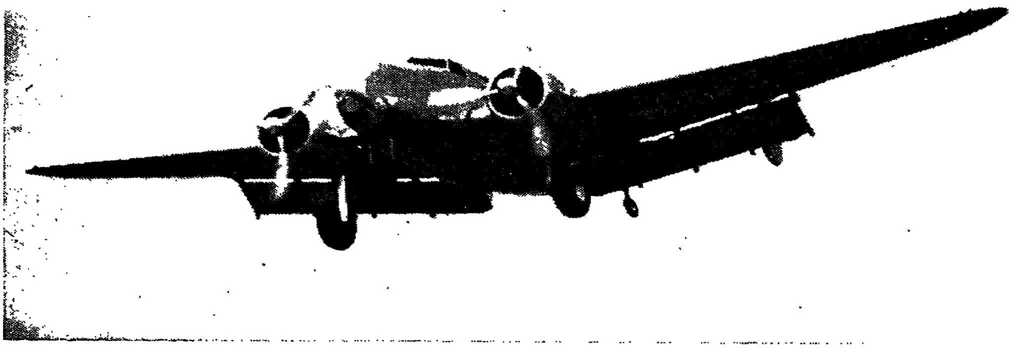


FIG. 126.—Lockheed Lodestar landing with flaps extended.

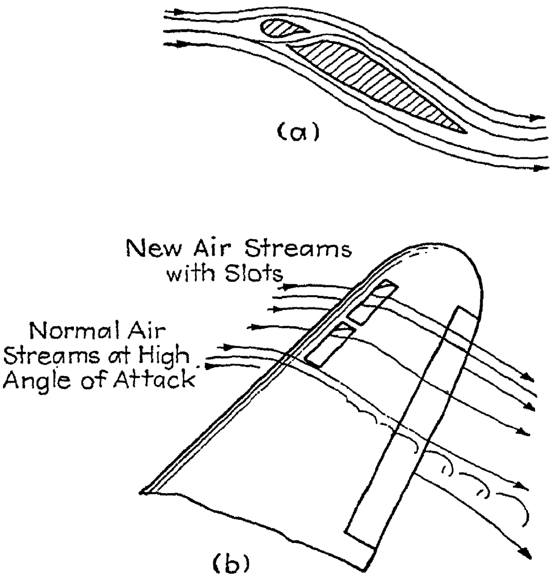


FIG. 127.—Wing slots.

principle as ailerons. By lowering the trailing edge of the wing the effective angle of attack is increased, giving greater lift. Three types of flap are shown in Fig. 123.

The increase in effective angle of attack with the use of flaps decreases the angle of stall (see Fig. 112).

2. Slots.—The angle of maximum lift, or stall angle, is determined by the tendency of the air flow to break down across the top of the wing. By permitting air from the bottom side of the wing to pass to the top side through slots in the wing (see Fig. 127), this tendency of the air flow to break down can be lessened. This increases the angle of stall, and therefore the maximum lift coefficient C_L (Fig. 112).

By combining both flaps and slots the angle of stall and the lift coefficient are both greatly increased (Fig. 112). For this reason slots are used on wing tips to permit aileron operation at landing. Slots are not used for the entire length of the wing because of increased weight and manufacturing costs.

DESIGN AND PERFORMANCE

The performance of any airplane is usually determined by consideration of the following items:

1. Maximum speed at sea level.
2. Maximum speed at cruising altitude.
3. Gross weight versus pay load.
4. Rate of climb at sea level and at altitudes.
5. Time to climb to altitudes.
6. "Service ceiling," or altitude at which the rate of climb is 100 f.p.m.
7. "Absolute ceiling," or the altitude beyond which the airplane cannot climb.
8. Landing speed.

These items are influenced by the design of and choice of the power-plant unit, wing design, and fuselage and components' design.

Power Plant

The factors of the power plant affecting the performance are

1. Maximum horsepower of engine.
2. Maximum weight of engine.
3. Change in horsepower with altitude.
4. Fuel and oil consumption.
5. Over-all drag of engine and its accessories, such as radiators and cowl.
6. Propeller selection.

Increased horsepower gives increased speed or improves performance. This increase in horsepower is not warranted if the weight increase of the engine is too great. Therefore, horsepower per pound is of vital importance to performance. Horsepower may be increased by increasing the r.p.m. However, each engine has certain structural limits beyond which it cannot go. Increased r.p.m. also increases propeller speed and decreases propeller efficiency. This may be corrected for by gearing the propeller shaft down to turn at less than engine speed. These gears increase engine weight, which does not warrant their use in low-horsepower engines. The horsepower of the engine can also be increased by increasing the compression ratio. Here detonation, due to fuel characteristics, and head strength limit the horsepower.

At present, radial air-cooled engines give greater horsepower per pound than in-line liquid engines, but radial engines offer greater drag than in-line engines with coolant radiator (if used). Because of these two conditions, the radial-engine manufacturer attempts to lower engine drag by improved cowling design, and the in-line engine manufacturer attempts to increase engine horsepower.

The change of horsepower with altitude was stressed in the discussion of lift, drag, and horsepower. From this it was evident that horsepower on nonsupercharged engines varies with altitude, as the density of air. The purpose of the supercharger is to pack more air into the engine to increase air density. This means that at sea level a supercharged engine can produce more horsepower than is needed to such an extent that if full horsepower at sea level were used the internal forces would destroy the engine. For this reason, supercharged engines are placarded for maximum r.p.m. and manifold pressure at sea level. By increasing the throttle setting with increase in altitude a constant horsepower can be maintained up to the critical altitude of the engine. At that altitude the supercharged effect ends, and the horsepower available again depends on air density. The critical altitude is of great importance to high-altitude fighters and bombers because of influence on speed at altitude.

Fuel and oil consumption is of vital importance because of its influence on weight, range, and endurance. Fuel consumption is a definite characteristic of each engine. At present, this

consumption is higher for air-cooled engines than for liquid-cooled engines, because the higher head temperatures of the air-cooled engine require richer mixture and the use of oil as a coolant.

Metal propellers are far more efficient than wooden propellers, because of thinner sections of greater accuracy. Fixed propellers are designed either for best climb or for best performance and cannot be designed for both. Best climb propellers require low blade angles for high r.p.m. and increased horsepower. Best performance and propellers require large blade angles at low r.p.m. and cruising horsepower. To overcome this condition and to improve take-off and cruise propeller efficiency, the controllable-pitch propeller was developed. Today this propeller will satisfy both cruise and climb conditions and can also be feathered while in flight. This may be done either by hydraulics or by electricity.

Wing Design

The efficiency of the wing and therefore the performance of the plane are affected by

1. Airfoil selection.
2. Wing form and construction.
3. Wing location.
4. Wing loads and aspect ratio (A.R.).

As stated at the beginning of this chapter the lift-drag characteristics of a wing are greatly affected by the shape of the airfoil. The National Advisory Committee for Aeronautics (NACA) has detailed information available on all leading wing sections. This information includes lift, drag, c.p. travel, and moment coefficient for various angles of attack, as well as all coordinates necessary to lay out the airfoil. The mechanic is interested mainly in the method required to lay out this section after it has been chosen by the designer (see Layout of Wing Profile, page 145). The designer selects the wing to fit his design problem.

The plan form of the wing may vary greatly. Figure 128 shows a group of the most popular forms:

Rectangular wings are used mainly on biplanes and high-wing monoplanes. Most of these planes are in the low-cost field. Because the wing loading is uniform from the center line of the

ship to the wing tip, this type of wing requires external bracing, which increases the wing drag. The biplane also has more drag than the monoplane (see Figs. 129 and 130).

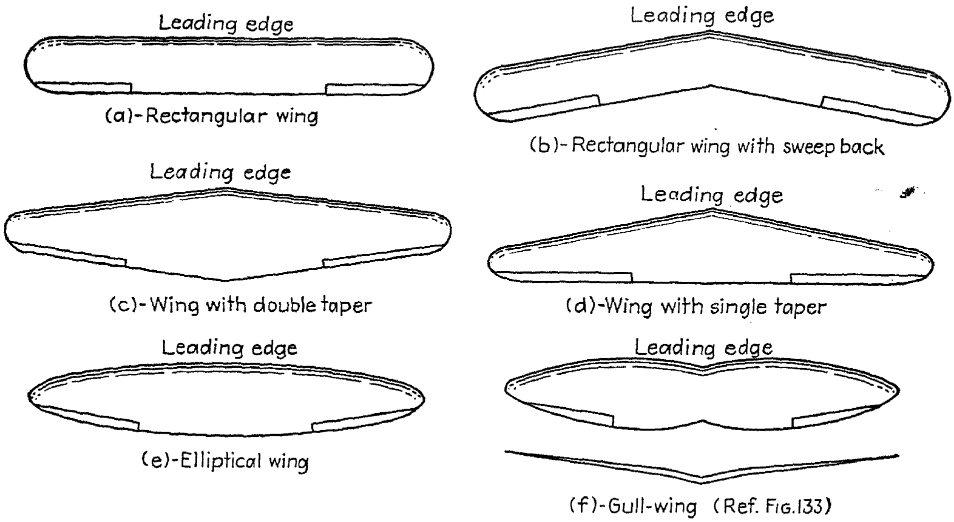


FIG. 128.—Popular wing forms.

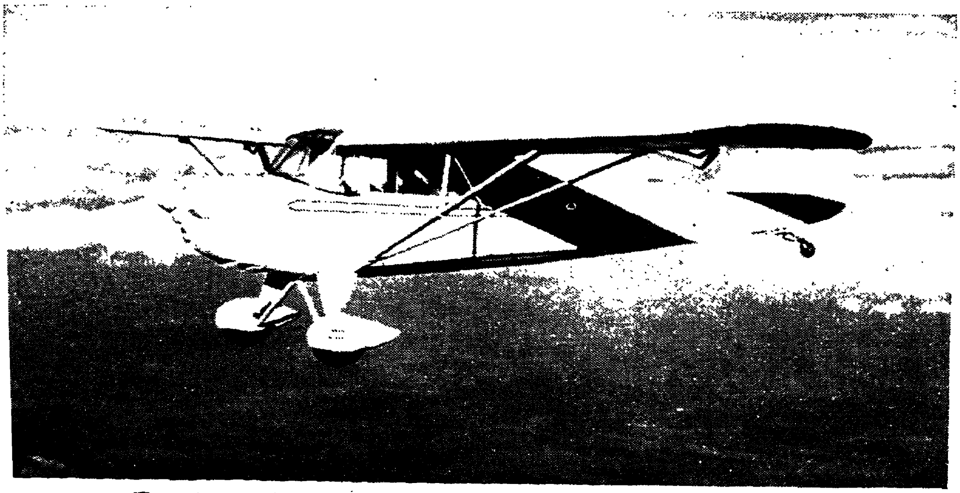


FIG. 129.—Aeronca Chief in flight—high-wing monoplane.

The tapered wing allows the designer to concentrate most of the wing loads close to the center line of the ship; it thus lends itself well to cantilever construction. This wing is very efficient

as is proved by its wide use on modern aircraft (see Figs. 122 and 131).

The elliptical wing is aerodynamically the most efficient, but manufacturing costs restrict it mainly to high-price fields (see Fig. 132).

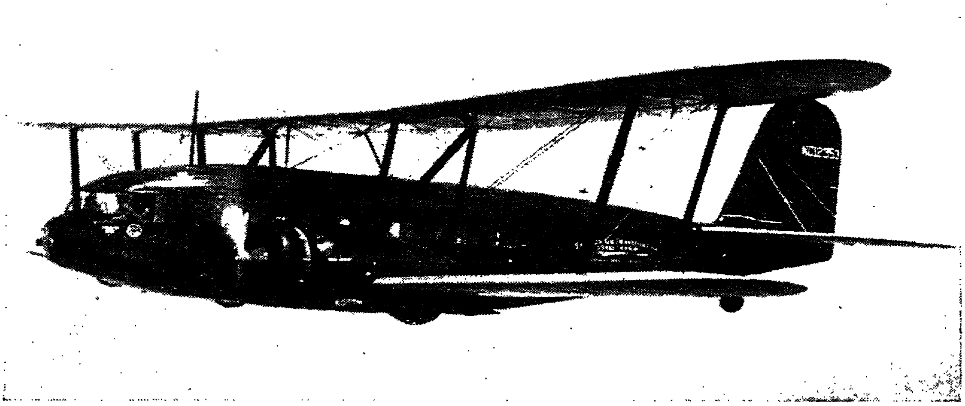


Fig. 130.—A Curtiss Condor fabric-covered biplane—one of the first large passenger transports. (*Courtesy of Eastern Air Lines, Inc.*)

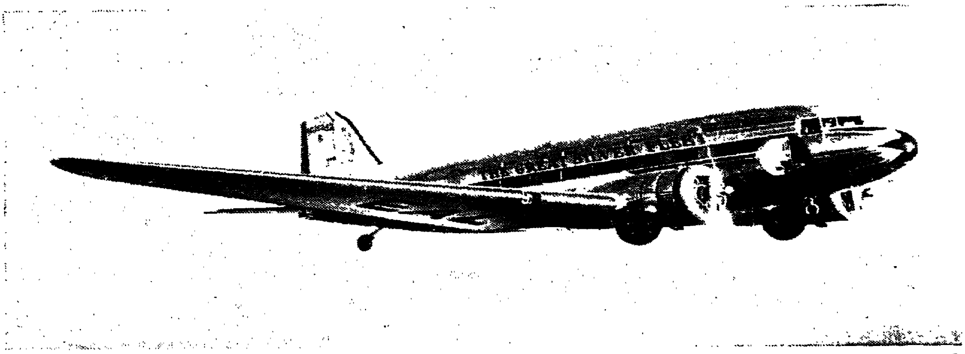


Fig. 131.—Low-wing monoplane with a straight trailing edge and a tapered leading edge (Fig. 128*d*). This is a Douglas DST (sleeper ship). The small windows above the large windows give light to the upper berths. (*Courtesy of Eastern Air Lines, Inc.*)

Wings may be located above, below, or on the thrust line. The latter is the most efficient aerodynamically but the most inefficient structurally. The high-wing monoplane is more stable than the low-wing monoplane, but the low wing monoplane lends itself well to manufacturing methods and is a very popular type (see Figs. 134, 131, and 135).

Aspect ratio (A.R.) is the ratio between the wing-span length and chord length; it may be expressed by the equation

$$\text{A.R.} = \frac{b}{c} = \frac{S}{b^2} \tag{54}$$

where A.R. = aspect ratio
b = wing span, ft.
c = mean chord, ft.
S = wing area, sq. ft.

A.R. has little effect on plane performance at low angles of attack but has a definite influence on wing drag at high angles of

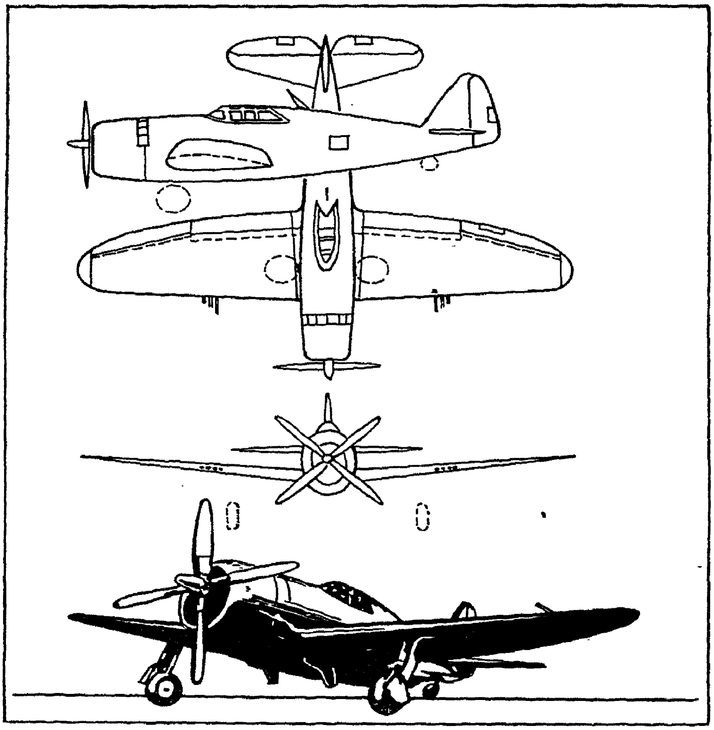


FIG. 132.—The Republic P-47 is a fast pursuit with an elliptical wing and full-trailing-edge flap.

attack. Low A.R. gives greater induced drag; large A.R. gives small induced drag. Average values of A.R. are 6 to 9.

From the equation $L = W = \frac{1}{2}\rho V^2 C_L$ it can be seen that the higher the wing loading the greater must be the speed for a given ship if the air density and C_L remain the same.

$$\text{Wing loading} = \frac{W}{S} = \frac{1}{2}\rho V^2 C_L \qquad (55)$$

This means that ships with high wing loadings will have high landing speeds and ships with low wing loading will have low landing speeds. This also holds true for cruising and maximum speeds.

Fuselage and Components

Since fuselage and component design vary, it would be very difficult to discuss them in detail. However, a well-rounded

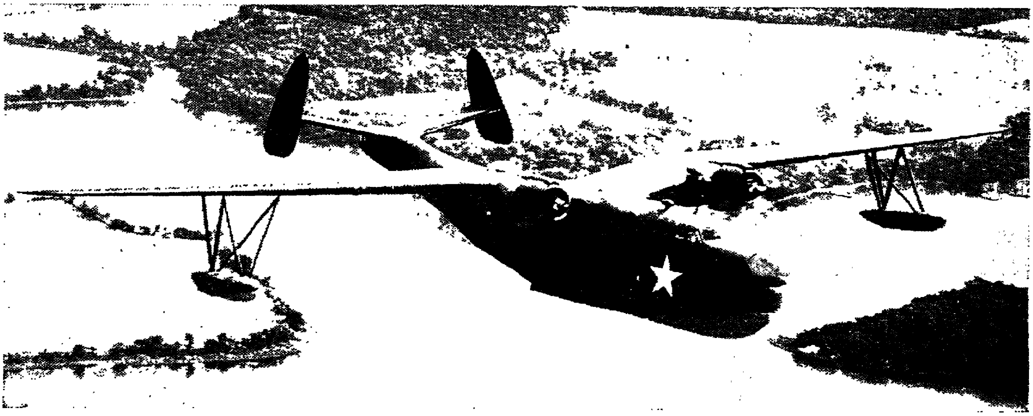


Fig. 133.—Navy Martin Patrol Boat employing a gull wing.

cigar type of fuselage, with very clean lines, no struts or wires, and retracted gear is the most efficient type.

Layout of Wing Profile

The dimensions for the layout of the upper and lower cambers of an airfoil are furnished by the NACA in percentages of the geometrical chord. In Table III, the column marked "Station" means the distance back from the leading edge, the column marked "Upper" means the distance above the chord line at each station, and the column marked "Lower" means the distance below the chord line at each station. These dimensions can be changed into inches by multiplying the percentages by the chord length in inches. For example, should the chord length be 5 ft., or 60 in., these dimensions in inches are given in tabular form in Table III. After these values have been obtained, lay out the section as follows (Fig. 136):

1. Draw line 0-0 60 in. long as the geometrical chord line.

TABLE III.—NACA 25012

Dimensions, per cent of chord			Dimensions, inches for 60-in. chord		
Station	Upper	Lower	Station	Upper	Lower
0	....	0	0	....	0
1.25	2.48	−1.39	0.75	1.49	−0.835
2.5	3.37	−1.94	1.50	2.02	−1.16
5.0	4.70	−2.49	3.0	2.82	−1.49
7.5	5.62	−2.82	4.5	3.37	−1.69
10.0	6.36	−3.04	6.0	3.82	−1.83
15	7.39	−3.33	9.0	4.44	−2.00
20	7.97	−3.54	12.0	4.78	−2.12
25	8.20	−3.68	15.0	4.91	−2.21
30	8.21	−3.79	18.0	4.93	−2.27
40	7.75	−3.87	24.0	4.65	−2.32
50	6.92	−3.67	30.0	4.15	−2.2
60	5.87	−3.27	36.0	3.52	−1.96
70	4.64	−2.70	42.0	2.78	−1.62
80	3.27	−1.97	48.0	1.97	−1.18
90	1.78	−1.13	54.0	1.07	−0.678
95	0.98	−0.64	57.0	0.59	−0.384
100	(0.13)	(−0.13)	60.0	(0.078)	(−0.078)

Leading-edge radius = 1.58
Slope of radius through end of chord = 0.0215

Leading-edge radius = 0.95 in.
Slope = 12°

2. Lay out the station lines from the leading edge with values from Table III.

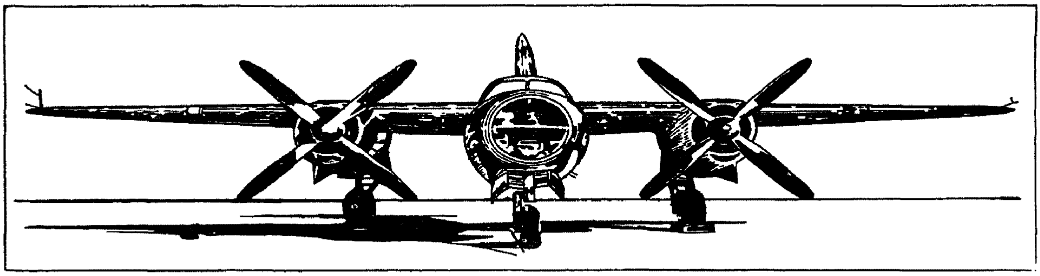


FIG. 134.—Ink sketch of an Army Martin high-wing bomber with a tricycle landing gear.

3. Lay out the upper and lower camber lines from the geometrical chord line with values from Table III.

4. Obtain the leading-edge radius by multiplying 60 × 0.0158, equals 0.95 in.

5. "Slope of radius through end of chord 0.215" means the angle whose tangent is .215 or 12°. Therefore, line 0-0 has a

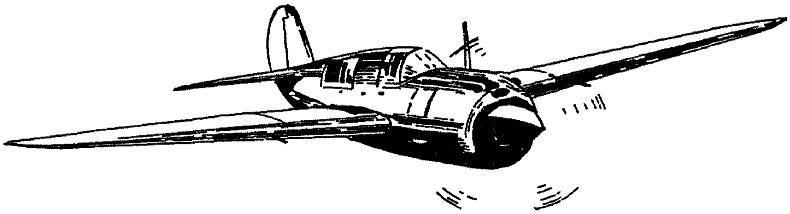


FIG. 135.—A Navy mid-wing dive bomber manufactured by Curtiss. Note the large spinner on the propeller.

slope of 12° (Fig. 136*b*). This gives the airfoil section without spar locations or angle of incidence.

Center of Gravity Location

In order to find the c.g. of an airplane, an accurate outline print or a schematic diagram of the ship should be available.

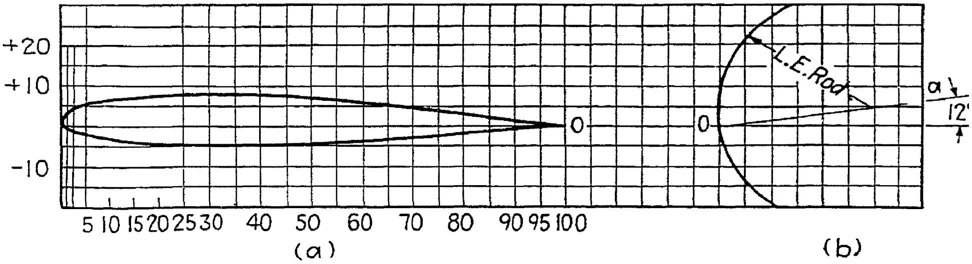


FIG. 136.—Profile of wing section NACA25012.

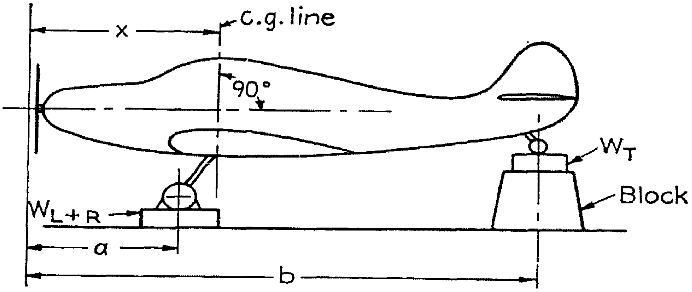


FIG. 137.—A ship on the scales in the level flight position.

Three scales are also needed, two of which must be able to support at least half the weight of the plane and the third the weight of the tail wheel.

Place the ship in flying position on the scales, and level it laterally. Information for placing the ship in this position should be furnished by the manufacturer (see Fig. 137).

Drop a plumb line from the center of the propeller hub, from the center of the landing-gear axle, and from the center of the tail-wheel axle. Measure distances a and b, and read weights W_L, W_R, and W_T. With this information write the equation below, and solve for x:

$$W_L + W_R + W_T = TW \tag{56}$$

$$aW_R + aW_L + bW_T = xTW \tag{57}$$

$$x = \frac{aW_R + aW_L + bW_T}{TW} \tag{58}$$

Where x is the distance the c.g. line is back from the hub of the propeller. Therefore, draw the c.g. line perpendicular to the thrust line.

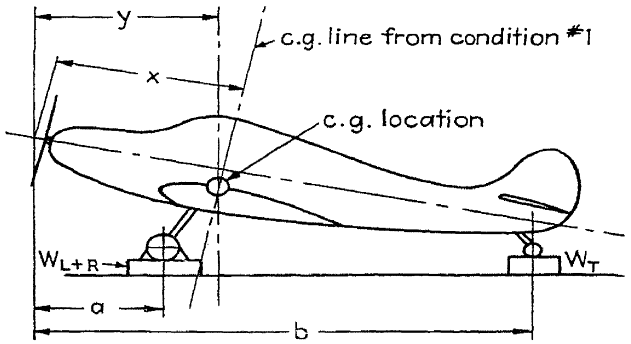


FIG. 138.—The ship in the three-point position.

Repeat the above process by placing the ship in the three-point position (Fig. 138). This time call the unknown distance y and draw the c.g. line perpendicular to the ground. The intersection of the c.g. lines for conditions 1 and 2 is the exact c.g. location fore and aft and vertically.

DEFINITIONS

Aileron: A hinged or pivoted movable auxiliary surface of an airplane, usually part of the trailing edge of a wing, the primary function of which is to impress a rolling moment on the airplane (Figs. 116 and 117).

Airfoil: Any surface designed to be projected through the air in order to produce a useful dynamic reaction (called *lift*) (Fig. 113).

Airfoil section, or profile: A cross-section of an airfoil (Fig. 111c).

Airplane: A mechanically driven aircraft heavier than air, fitted with fixed wings, and supported by the dynamic action of the air.

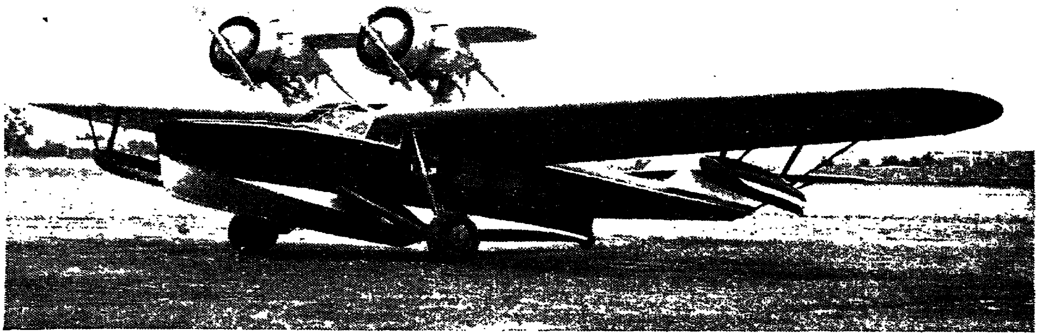


FIG. 139.—Douglas Dolphin amphibian.

Air speed: The speed of an aircraft relative to the air. Its symbol is V.

Amphibian: An airplane designed to rise from and alight on either land or water (Fig. 139).

Angle, aileron: The acute angle between the aileron and the wing. It is positive when the trailing edge is pulled down.

Angle, dihedral: The acute angle between the transverse reference line in the wing surface and the lateral axis of the airplane projected on a plane perpendicular to the longitudinal axis. The dihedral angle is positive when the upper obtuse angle for the two wings is less than 180° (Fig. 118).

Angle, elevator: The acute angle between the elevator and the stabilizer. It is positive when the trailing edge of the elevator is below the neutral position.

Angle, rudder: The acute angle between the rudder and the plane of symmetry of the aircraft. It is positive when the trailing edge moves to the left with reference to the normal position of the pilot.

Angle of attack: The acute angle between the chord of an airfoil and the air stream. Its symbol is α (Fig. 111).

Angle of incidence: The acute angle between the plane of the wing chord and the longitudinal axis. It may differ for each wing.

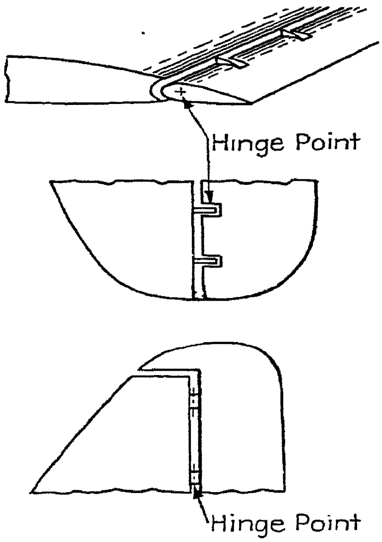


FIG. 140.—Two types of balanced surfaces found in wide use today. By placing part of the surface ahead of the hinge point, air loads can be used to help operate the controls. Some manufacturers also install weights in this portion of the surface.

Angle of stabilizer setting: The acute angle between the line of thrust of an airplane and the chord of the stabilizer (Fig. 121).

Aspect ratio: The ratio of span to mean chord of an airfoil; also, the ratio of the square of the span to the area of an airfoil.

Balanced surface: A control surface that extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge.

Bay: A portion of a fuselage between adjacent bulkheads or adjacent struts or frame positions.

Blade back: The cambered side of a propeller blade, corresponding to the upper surface of an airfoil (Fig. 114).

Blade face: The surface of a propeller blade, corresponding to the lower surface of an airfoil (Fig. 114).

Body: The fuselage or hull (including cowling and covering) or nacelle (including cowling and covering) and nacelle mounting.

Cabane: A pyramidal framework for supporting the wings at the fuselage. Also applied to the system of trussing used to support overhang in a wing (Fig. 141*a*).

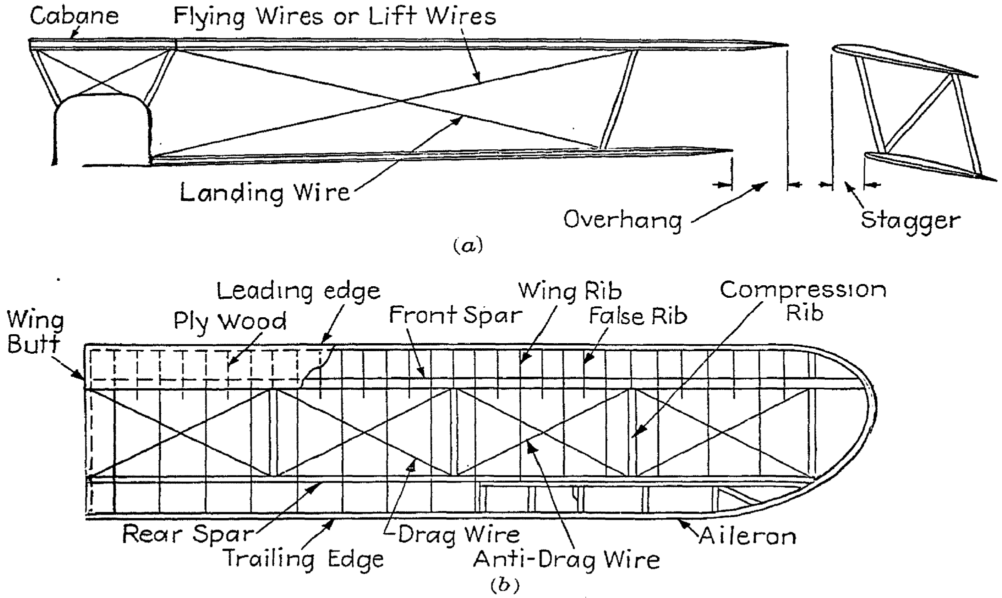


FIG. 141.—(*a*) Parts of a biplane. (*b*) Parts of a fabric-covered wing.

Camber: The rise of the curve of an airfoil section from its chord, usually expressed in percentage of the chord (Fig. 111*c*). "Top camber" refers to the upper surface of an airfoil, and "bottom camber" to the lower surface; "mean camber" is the mean of these two.

Chord (of an airfoil section): A straight line joining the leading and trailing edges of the airfoil. (These edges may be defined, for this purpose, as the two points in the section that are farthest apart.)

Control column, or yoke: A control lever with a rotatable wheel mounted at its upper end (see Control stick). Pitching is controlled by fore-and-aft movement of the column; rolling, by rotation of the wheel (Fig. 142).

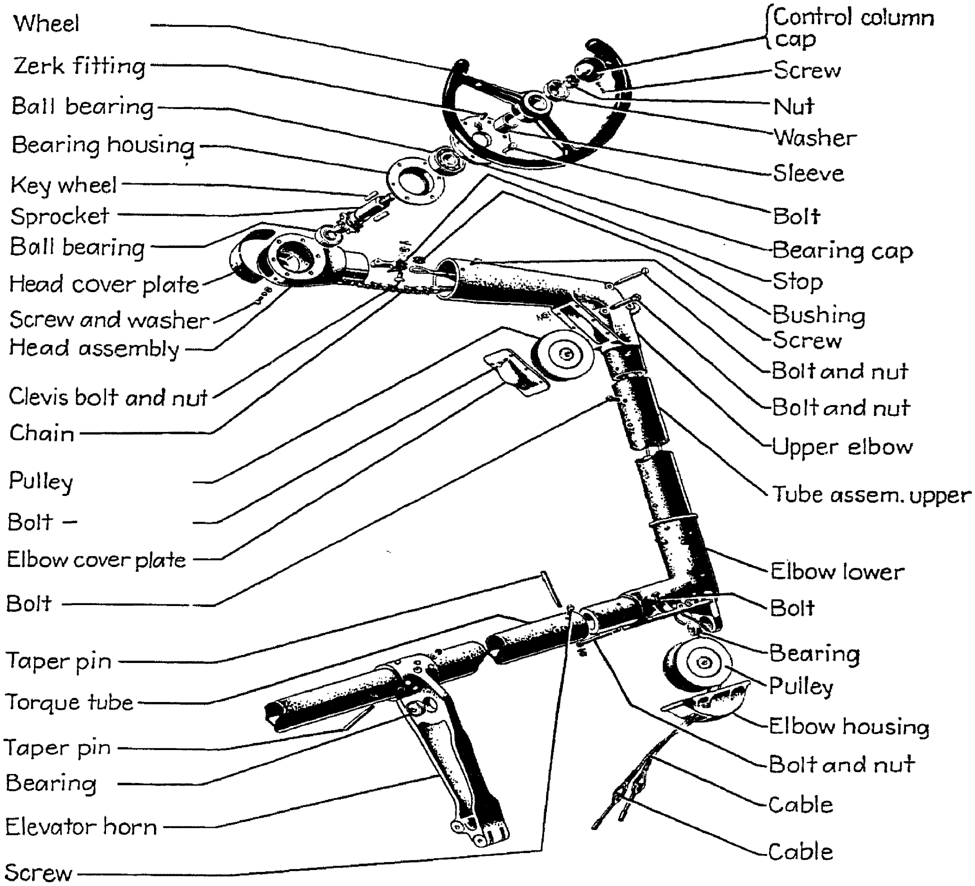


FIG. 142.—Control column for a Douglas DC-3.

Control stick: The vertical lever by means of which the longitudinal internal controls of an airplane are operated. Pitching is controlled by a fore-and-aft movement of the stick, rolling by a side-to-side movement (Fig. 116).

Control surface: A movable surface designed to be rotated or otherwise moved by the pilot in order to change the attitude of the airplane (Fig. 116).

Controls: A general term applying to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.

Controllability: The quality of an airplane that makes it possible for the pilot to change its attitude easily and with the exertion of but little force.

Cowling: A removable covering that extends over or around the engine (Fig. 122).

Decalage: The acute angle between the wing chords or between the wing and stabilizer.

Drag strut: A fore-and-aft member of the internal bracing.

Elevator: A movable auxiliary surface used to impress a pitching moment on the aircraft. It is usually hinged to the stabilizer (Figs. 116, 122, and 143).

Fairing: An auxiliary member or structure whose primary function is to reduce head resistance or drag of the part to which it is fitted. In general, it does not bear any stress.

Fins: Small fixed surfaces, attached to different parts of aircraft, parallel to the longitudinal axis, in order to secure stability, *e.g.*, tail fins and skid fins. Fins are in the great majority of cases substantially vertical and are sometimes adjustable (Figs. 116 and 122).

Fire wall: A fire-resisting material between the engine and the fuselage.

Fuselage: The elongated structure, or approximately a streamline form, to which are attached the wings and tail unit of an airplane. In general, it contains the power plant, passengers, cargo, etc.

Gap: The distance between the planes of the chords of the upper and lower wings of a biplane measured along a line perpendicular to the chord of the upper wing at any designated point of its leading edge. Its symbol is G (Fig. 141*a*).

Horsepower of an engine, maximum: The maximum horsepower that an engine can develop.

Horsepower of an engine, rated: The average horsepower developed by an engine of a given type in passing the standard 50-hr. endurance test.

Landing gear: The understructure that supports the weight of an aircraft when in contact with the surface of the land or water and that reduces the shock of landing. There are five common types, the boat, float, skin, wheel, and ski types.

Leading edge: The foremost edge of an airfoil or propeller blade; also called *entering edge* (Fig. 111*c*).

Load, pay: That part of the useful load from which revenue is derived, *viz.*, passengers and freight.

Load, useful: The crew and passengers, oil and fuel, ballast, and other than emergency, ordnance, and portable equipment.

Longeron: The fore-and-aft member of the framing of a fuselage.

Maneuverability: That quality in an airplane which makes it possible for the pilot to change its attitude rapidly.

Monoplane: An airplane that has but one main supporting surface, sometimes divided into two parts by the fuselage.

Multiplane: An airplane with two or more main supporting surfaces placed one above the other.

Nacelle: An enclosed shelter for a power plant. A nacelle is usually shorter than a fuselage and does not carry the tail unit (Fig. 122).

Nose-heavy: The condition of an aircraft in which, in normal flight, the distribution of forces is such that the nose tends to drop if the longitudinal control is released.

Overhang: One-half the distance in span of any two main supporting surfaces of an airplane (Fig. 141*a*).

Pusher airplane: An airplane with the propeller or propellers in the rear of the main supporting surfaces.

Rate of climb: The vertical component of the air speed of an aircraft, *i.e.*, its vertical velocity with reference to the air.

Rudder: A movable auxiliary airfoil, the function of which is to impress a yawing moment on the aircraft in normal flight (Figs. 116 and 122).

Rudder pedal: The foot pedal by means of which the control cables leading to the rudder are operated.

Seaplane: Any airplane designed to rise from and alight on the water. This general term applies to both boat and float types, though the boat type is usually designated as a *flying boat* (Fig. 133).

Shock absorber: A device incorporated in the landing gear of an airplane to reduce shock imposed on the structure in landing and take-off (see Chap. V, Hydraulics).

Slip stream: The stream of air driven behind by the propeller.

Span (airfoil): The lateral dimension of an airfoil; *i.e.*, its dimension perpendicular to its chord. Its symbol is b.

Spinner: A fairing of approximately conical form, which is fitted to the propeller boss and revolves with the propeller.

Stabilizer: A normally fixed airfoil whose function is to lessen the pitching motion. It is usually located at the rear of an aircraft and is approximately parallel to the plane of the longitudinal and lateral axes (Figs. 116 and 143).

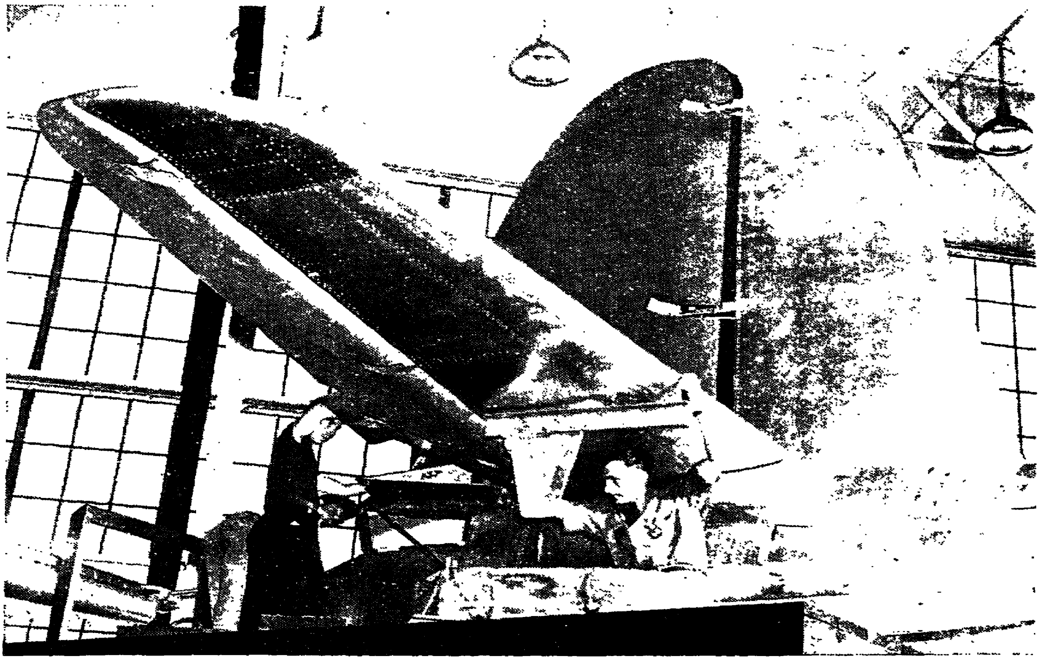


FIG. 143.—Empennage of a Martin twin-engine army bomber. The man on the left is adjusting an elevator movable tab. A form of balanced rudder and elevator is also shown.

Stagger: The amount of advance of the leading edge of an upper wing of a biplane over that of a lower, expressed either in percentage of gap or in

degrees. It is considered positive when the upper wing is forward (Fig. 141*a*).

Stalling: A term describing the condition of an airplane that from any cause has lost the air speed necessary for control.

Tail-heavy: A condition which in normal flight causes the tail to sink if the longitudinal control is released; or a condition in which the pilot has to exert a push on the control stick to keep the given attitude.

Tipping (propeller): A sheet-metal (or equivalent) protective covering of the blade of a propeller near the tip, extending a short distance along the trailing edge and a considerable distance along the leading edge.

Tractor airplane: An airplane with the propeller or propellers forward of the main supporting surfaces.

Trailing edge: The rearmost edge of an airfoil or propeller blade (Fig. 141*b*).

Warp: To change the form of a wing by twisting it. Warping is sometimes used to maintain the lateral equilibrium of an airplane.

Wash: The disturbance in the air produced by the passage of an airfoil; also called the *wake*, in the general case for any solid body.

Washin: Permanent warping of a wing, which results in an increase in the angle of attack near the tip.

Wing loading: The gross weight of an airplane, fully loaded, divided by the area of the supporting surface. The area used in computing the wing loading should include ailerons, but not the stabilizer or elevators.

Wing spars: The principal transverse structural members of the wing assembly of an airplane (Fig. 141*b*).

Wing heavy: A condition in which the left or right wing of an aircraft sinks below its normal level of flight position when the controls are set to maintain level flight. The condition in which the pilot has to exert a lateral force on the control stick to keep the lateral axis of aircraft horizontal when in flight.

Wing compression rib: A wing rib that functions as a strut opposing internal drag wires (Fig. 141*b*).

Wing false rib: A short fore-and-aft rib, sometimes referred to as an *incomplete rib*, which frequently consists of only a curved strip of wood extending from the leading edge of the wing to the front spar of that wing. The rib is so designed as to maintain the desired form of the wing at its point of greatest curvature (Fig. 141*b*).

Wing rib: A horizontal, structural member of framework, so designed and placed as to add strength and stability to it (Fig. 141*b*).

Wire antidrag: A wire, usually in the wing, designed to resist forces acting parallel to the chord of the wing and in the same direction as that of the flight (Fig. 141*b*).

Wire drag, internal: That wire which counteracts drag in a wing (Fig. 141*b*).

Wire landing: A wire designed to support the wing while on the ground, or one designed to oppose the lift wire and prevent distortion of the structure

Wire lift: A wire designed to transfer the lift forces from the wing to the fuselage while the ship is in flight. It is opposite to the landing wire (Fig. 141*a*).

CHAPTER IV

AIRPLANE CONSTRUCTION AND MATERIALS

The first airplanes were built mainly of wood, mild carbon steel being used for fittings only. These ships retained their shape by means of internal and external brace wires. With the improvement of materials the airplane also improved, and the wooden structure was replaced with a steel tubular structure. Today this in turn has been replaced by aluminum and aluminum-alloy structures, known as *monocoque* or *semimonocoque*. Aluminum, however, is only one of the many materials used in the manufacture of the modern airplane.

AIRCRAFT STRUCTURE

The structure of the average airplane can be broken down into several small components as follows: fuselage, wings, empennage, and engine section (power plant).

Fuselage

The fuselage is that part of the airplane to which all components are added. It may be compared to the backbone of a fish.

Early airplanes had no fuselage but attached all units to the wings. The pilot sat in front in the air stream. When passengers and cargo were added, it became necessary to enclose them in some manner, to reduce air drag. This gave birth to the early all-wood fuselage, held together by wooden cross-bracing and piano wire. This framework was covered with fabric, usually silk, and was a crude sight in comparison with the modern day air liner. The wood was presently replaced with a welded steel-tube structure, and the silk (later linen) with a cotton fabric, doped to give a highly polished, taut surface. This type of construction is still in use in the low-price field (Fig. 129). However, when longer service, greater comfort, and higher performance are required, the aluminum fuselage has replaced the steel-tube fuselage. The frame of the aluminum

structure is composed of bulkheads, formers, and stringers, riveted together. Over this, sheet aluminum is riveted. A

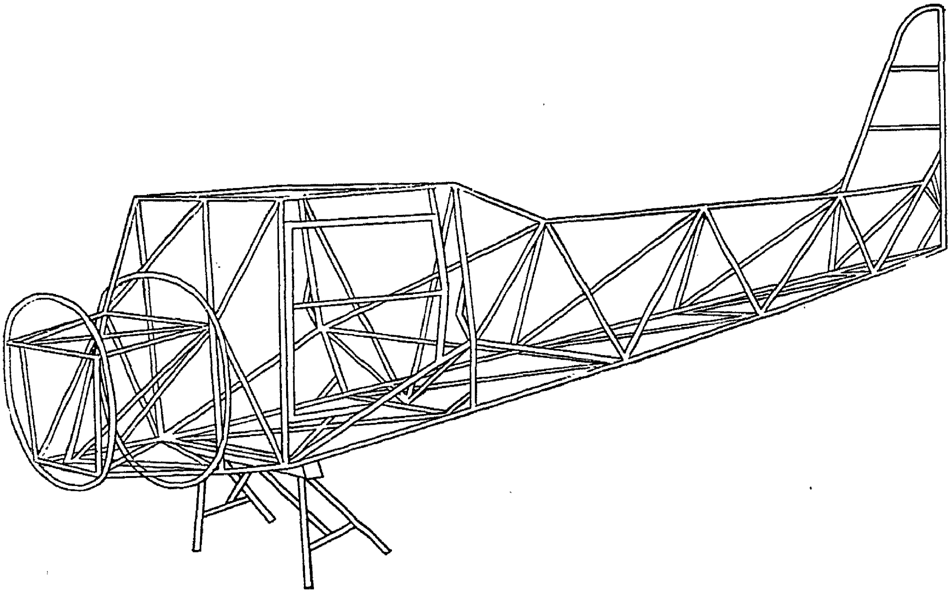


FIG. 144.—Welded-steel-tube fuselage of an Aeronca Chief.

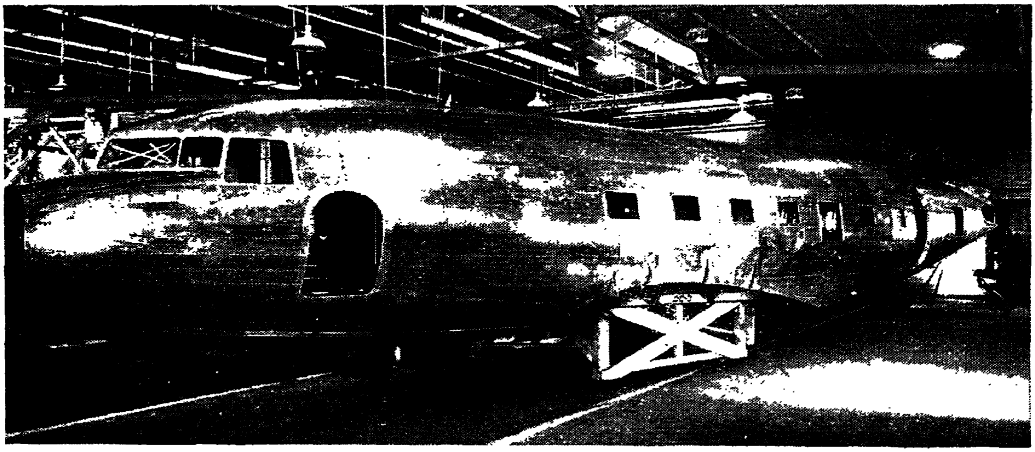


FIG. 145.—A Douglas DC-3 aluminum semimonocoque fuselage without center section or empennage.

typical welded fuselage is shown in Fig. 144. Figures 145 and 146 show the outside and inside of an aluminum-alloy semimonocoque fuselage. The formers and stringers can clearly be seen in Fig. 146.

The fuselage accommodates the pilot, copilot, and other members of the crew and the passengers and cargo. Some ships also require additional equipment, as radio, gas, oil, and electrical equipment and de-icer and hydraulic systems. The amount

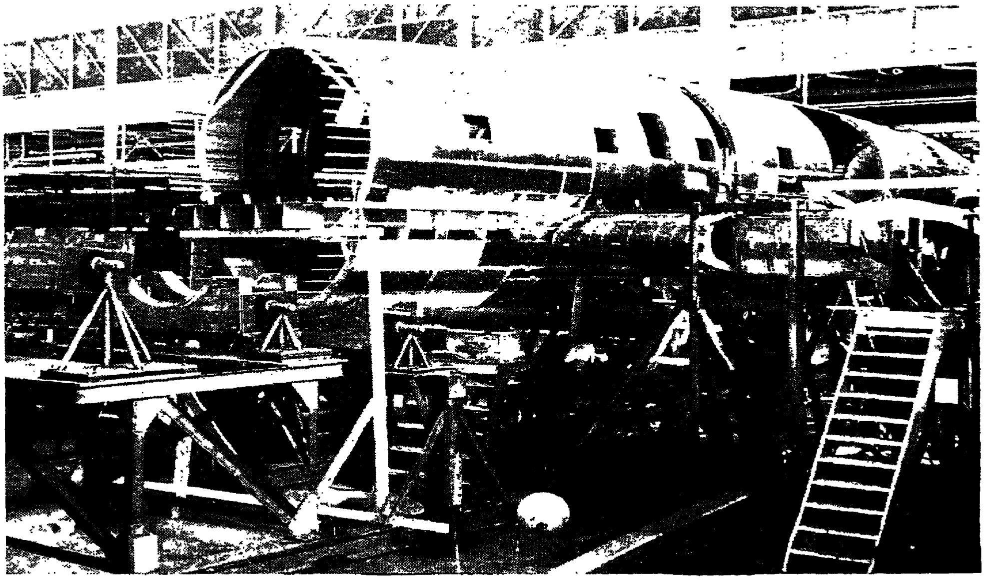


FIG. 146.—Assembling a Curtiss C-46 cargo ship. The formers, stringers, and many other parts of semimonocoque construction can be clearly seen.

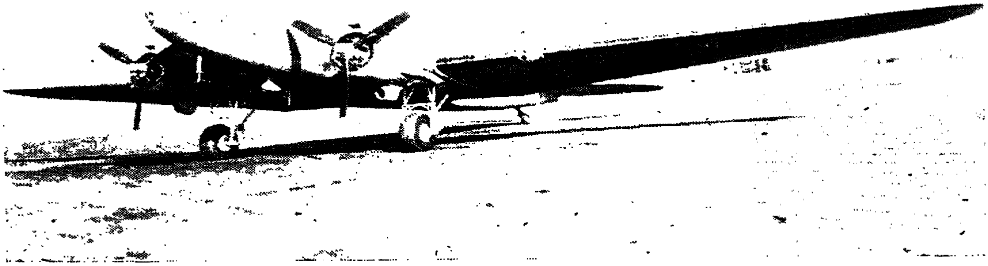


FIG. 147.—Conventional type landing gear on a Douglas cargo ship.

and location of such equipment depend entirely upon the designer and the use for which the ship is manufactured. In general, the pilot and copilot sit in the nose, and the passengers sit aft. Cargo space may be in the nose, behind the pilot, aft of the passengers, or in the belly.

All ships must have some form of alighting gear. Seaplanes use floats, and flying boats use their hulls. Landplanes may use wheels or skis. Wheel alighting gears may be either the conventional type with a tail wheel or tail skid or the new tricycle type with a nose wheel. Landing gears may be fixed or retractable. Because of higher performance, military and airline aircraft employ retractable gears. Electrical, hydraulic, or mechanical units are used to operate retractable gears. They may be attached either to the fuselage or to the wing, or both.

Wings

The first wings were flimsy affairs of flat cross-sections, employing two spars, solid ribs, and piano-wire bracing. To

Fig. 148.—A Douglas light bomber with a tricycle landing gear.

make it tight, the fabric (usually silk) was laced on. With the establishment of wind tunnels in which to conduct tests, airfoils of improved cross-section were developed. Three of these are shown in Fig. 113. The thicker sections made possible better wing construction.

The new wings with the improved profiles were still manufactured mainly of wood, because of light weight and ease of manufacture. Such a wing is shown in Fig. 141. The spars were solid wooden beams; the ribs were the truss type as shown in Fig. 149, and the compression ribs were solid wood or steel tube. The ailerons were of the same construction and were operated by control cables routed around pulleys. The entire structure was covered with fabric (now cotton) and doped to

give greater life and better performance. Today such construction is still used in the low-price field, but aluminum is replacing many of the parts.

The modern air liner, fighter, and bomber use aluminum almost entirely in the construction of their wings. The spars

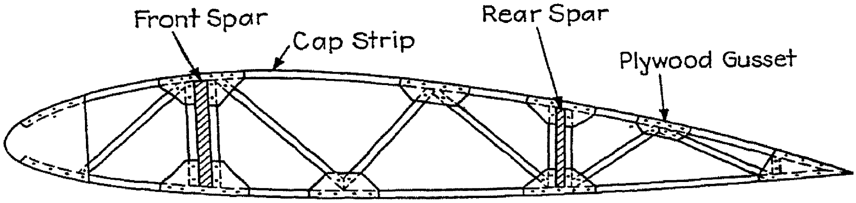


FIG. 149.—Truss type wing rib.

are two or three aluminum I beams or trusses. To these, many ribs of similar construction are attached. To help form the skin and to give greater strength, bulb-angle stringers are attached spar-wise to the ribs. Over this structure aluminum-alloy sheets are riveted to form the skin. Because the skin now carries most of the loads, internal drag bracing can be omitted.

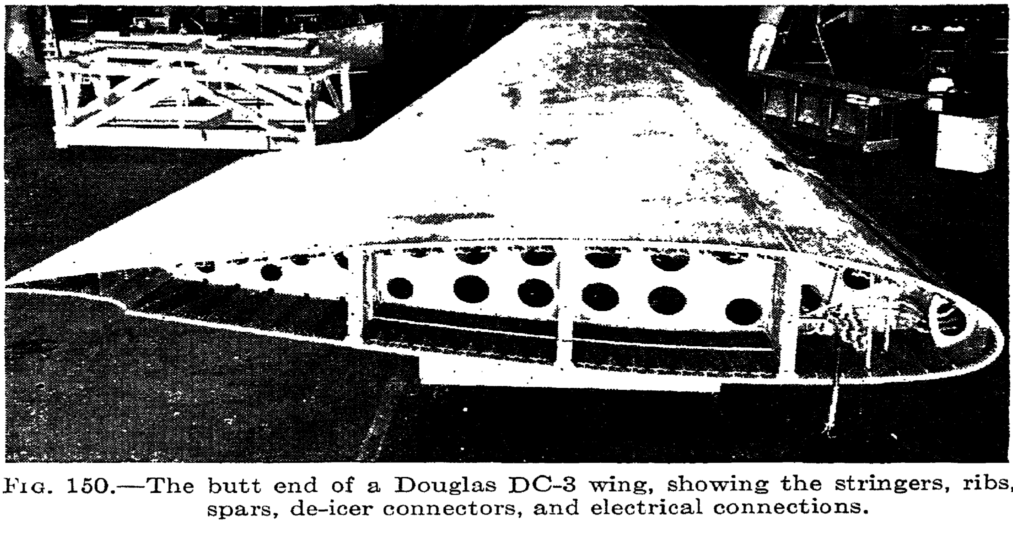


FIG. 150.—The butt end of a Douglas DC-3 wing, showing the stringers, ribs, spars, de-icer connectors, and electrical connections.

The aluminum wings give a higher performing, more durable structure. The aileron may be of aluminum structure fabric covered or all aluminum. If lower landing speeds are desired flaps that are either all aluminum or fabric covered can be attached. The ailerons are still operated by control cables,

but the flaps may be operated by mechanical, hydraulic, or electrical means.

Empennage

The empennage, or tail group, is made up of the vertical and horizontal stabilizers, the rudder, and the elevators. Like the

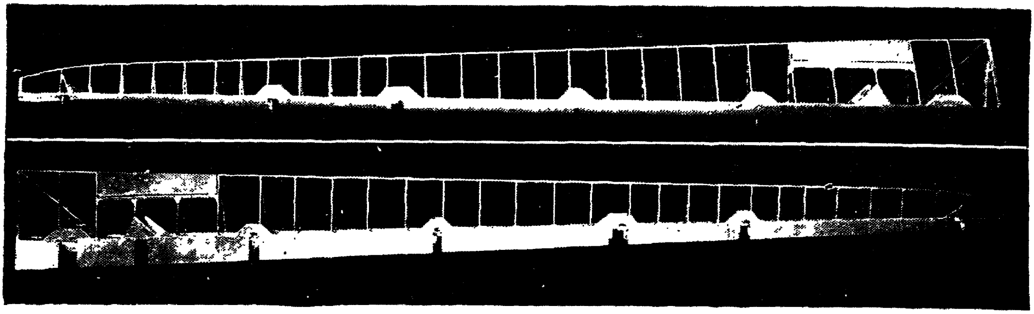


Fig. 151.—Top and bottom views of a Douglas DC-3 aileron uncovered.

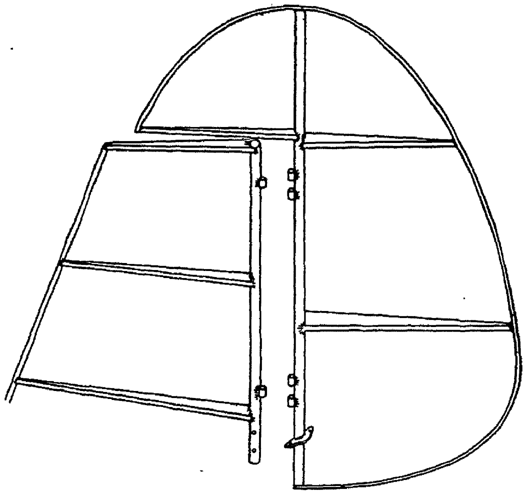


Fig. 152.—Welded-steel-tube fin and rudder.

wing and fuselage, the early tail groups were manufactured of wood. When the fuselage was converted to a welded-tube structure, the empennage was also converted.

The torque tube was a steel tube of large diameter to which chrome-moly or mild-steel ribs were welded. To the ribs the leading edge, a steel tube of small diameter, was welded. Hinges of small-diameter large-wall tube were welded to the torque

tube. The entire structure was covered with cotton fabric and doped. All units of this group are virtually the same. Again, this type of structure is still used in the low-price field but has been replaced in the higher brackets with aluminum. The aluminum structure is the same here as for the wings.

FIG. 153.—An all-aluminum empennage on a Lockheed 14-passenger ship. The slots, flaps, and retracted gear are also shown.

The movable surfaces are operated by cables in the same manner as the ailerons. In a few instances, torque tubes and bell cranks replace the cables.

POWER PLANT

Power plants in general are attached to a welded steel-tube structure called the *engine mount.* These mounts in turn are bolted to the airplane. Between the engine and the mount, rubber shock mounts are placed to help remove some of the vibration produced by the engine. Engines range from small 55-hp. opposed engines to a 2,000-hp. twin-row radial engine.

To the engines are attached the accessories, which vary from a carburetor, oil pump, and magnetos on the small engine, to

carburetor, oil pumps, fuel pumps, hydraulic pumps, vacuum pump, magnetos, starters, generators, and propeller governors for the larger engines. On single-engine aircraft the engine mount is attached to the nose of the fuselage. On multiengine craft the engine mounts are attached to barrel-shaped aluminum cylinders called *nacelles,* which are riveted either to the leading

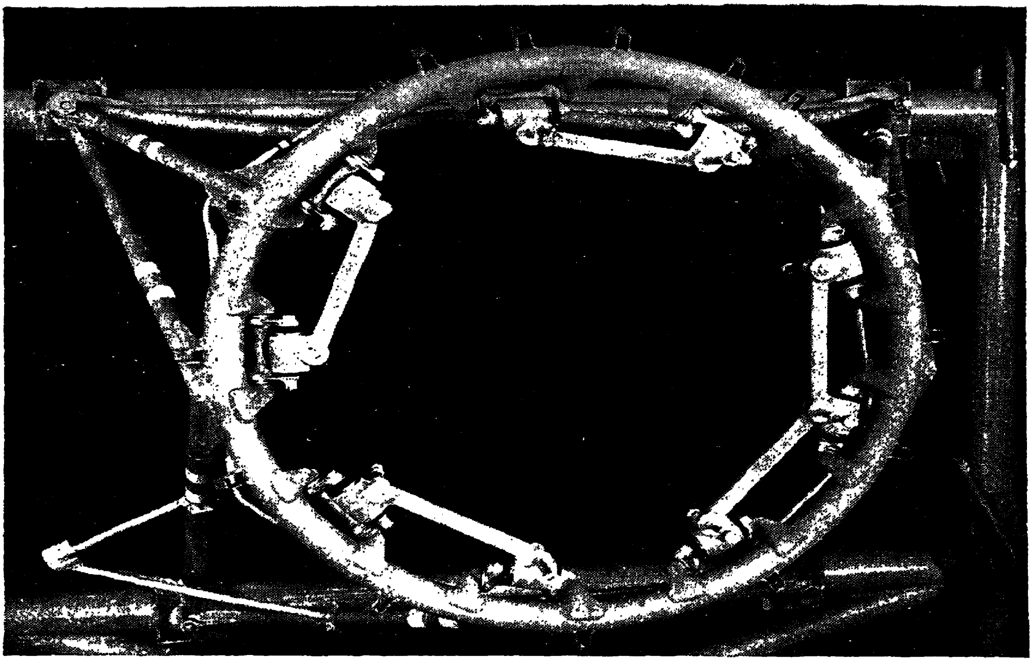


FIG. 154.—A welded-steel-tube engine mount with the rubber shock mounts installed to receive the engine. (*Courtesy of Lord Mfg. Co.*)

edge or to the trailing edge of the wing. The engine controls are operated by cable, electrical, and hydraulic systems. The power plant will be covered in greater detail in a later chapter.

MATERIALS

It is impossible for the mechanic to inspect, maintain, overhaul, or repair an airplane without a basic knowledge of the materials used in its construction. Therefore, this chapter will attempt to cover some of the most important materials used.

The first airplanes were simple machines and required very few materials. Today's planes, however, are complicated and require many materials of various properties, heat treatments, and use.

These materials are furnished the airplane manufacturer by companies all over the country. The mechanic makes repairs at fields located great distances from the manufacturer or from his main overhaul base. In order that all materials used by the mechanic will have the same physical and chemical properties as those furnished by the manufacturer and in order that all materials of the same classification used by the manufacturer will be exactly the same, the Army and Navy have established a minimum standard for materials known as the Army-Navy

FIG. 155.—A Lord bonded rubber shock mount. Engine vibration is reduced in this manner to give a quieter and more comfortable airplane.

Specifications, or "AN Specs." These specifications cover not only a wide range of structural and nonstructural materials used in aircraft construction but also many miscellaneous parts, as rivets, bolts, and nuts.

The "AN Specs." are only one of many standard systems in use in the aeronautical industry. Some of the other systems are the Naval Aircraft Factory Specifications, abbreviated NAF; the Federal Specifications, abbreviated Fed.; the Air Corps Specifications, abbreviated AC; and the Society of Automotive Engineers numbers, abbreviated S.A.E. Additional information on the AN Specifications is given in the Appendix. Other materials are listed below in alphabetical order. Materials classified as metals will be covered in the section of this chapter

FIG. 156.—A twin-row radial engine being installed in a medium Martin bomber.

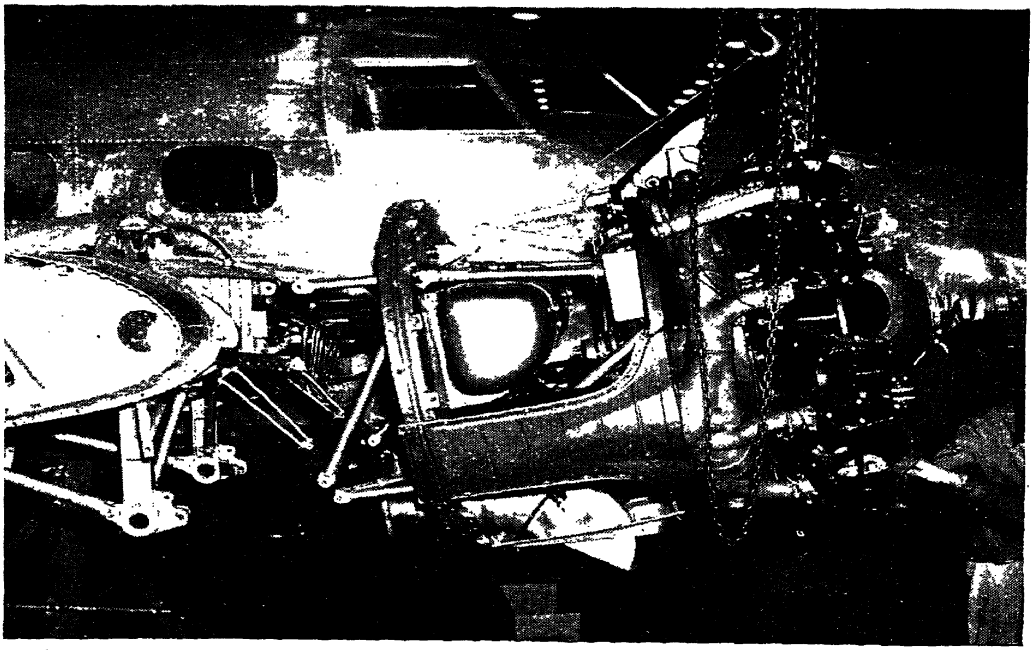


FIG. 157.—Attaching the engine and mount to the nacelle of a 14-passenger Lockheed air liner. Engine-control rods, oil tank, corrosion-resistant exhaust collector ring, and many other parts are visible.

on that subject (page 189). Miscellaneous small parts will be covered under Hardware (page 179).

Cable.

With the ever increasing tendency toward semimonocoque construction, the use of aircraft cable and tie rods to transmit structural loads is becoming very limited. However, it still predominates for the operation of controls.

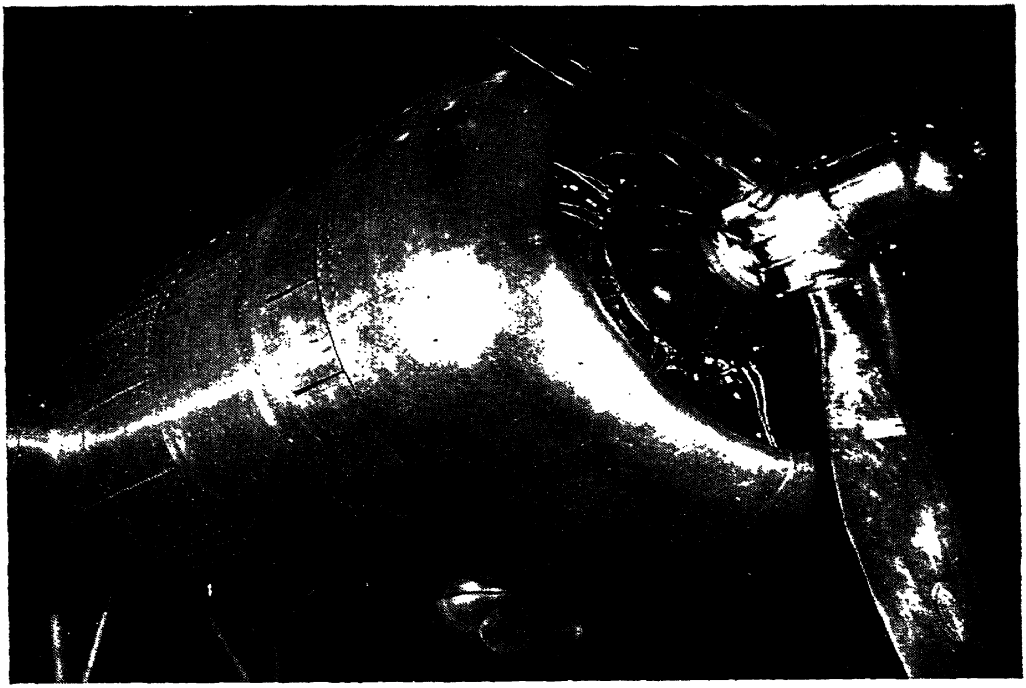


FIG. 158.—Wright Cyclone engine installation in a Douglas DC-3. The engine is equipped with a Hamilton Standard full-feathering propeller. Note the shape of the cowling. The cowl flaps are closed.

High Carbon Steel Aircraft Wire.—High carbon steel wire, referred to as *piano wire*, is a high-strength steel wire. It may be obtained in any standard size from 0.032 to 0.306 in. For a table of sizes and strength, see Table IV (page 167).

This wire is copper, chrome, or cadmium plated to prevent rust and to aid in soldering. It was extensively used in old-type construction for internal bracing of the wings and fuselage. However, with improved methods of construction, it has been

replaced with tie rods, which will be discussed later. It is still used, however, for springs, hinge pins, cowl pins, etc. Since it is very brittle, it is difficult to handle without the required tools. Under no circumstances should it be bent at sharp angles, for it has a tendency to break at such points.

FIG. 159.—High-carbon steel-wire terminal.

A high carbon steel-wire terminal is shown in Fig. 159.

Nonflexible Cable.—Cable is formed by winding groups of very fine wires around a center wire in the form of a helix. The center wire is called the *core wire,* and each group of wires is

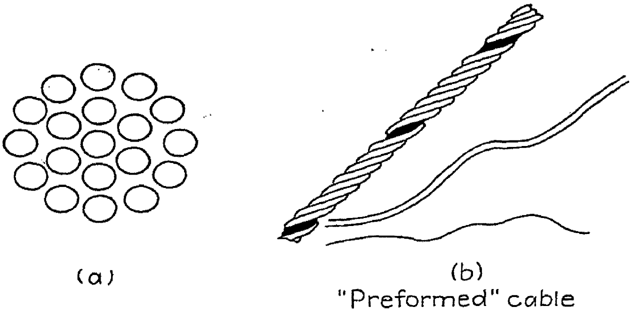


FIG. 160.—This figure shows the shape of a preformed cable strand.

called a *strand.* A number of strands are wound around a *core strand* in a helix to form the cable. Cable is classified according to its construction as 1 × 19, 7 × 19, etc. The first number gives the number of strands, and the second number gives the number of wires in each strand.

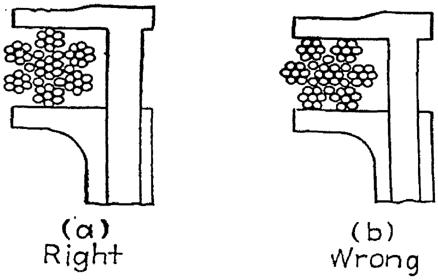


FIG. 161.—The right and wrong way to measure cable.

In the construction of early planes nonflexible cable was extensively used, but like piano wire it has been replaced almost entirely by tie rods. Nonflexible cable is 1 × 19; *i.e.*, the cable has one strand of 19 wires. As the name implies, this cable is not very flexible and can be used only for bracing, etc. It is made of high carbon steel or stainless steel. *preformed* or *nonpreformed*.

To increase the flexibility of the cable and to help prevent it from untwisting, sometimes, before forming takes place, the cable is formed into the helical shape it will take after forming. This is known as *preforming*. Figure 160 shows a preformed cable. A table of cable sizes and strengths is given in Table IV. In measuring the diameter of a cable, the distance across the flats must not be taken, for the diameter of a cable is the diameter of the circle that surrounds it (see Fig. 161).

Nonflexible cable cannot be spliced but must have a wrapped and soldered type of terminal. Brake, water rudder controls,

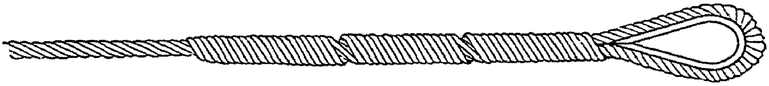


FIG. 162.—Wrap splice; solder well after wrapping with brass safety wire.

and $\frac{1}{16}$-in. flexible cables may also employ this method. This splice is shown in Fig. 162.

TABLE IV.—WIRE AND CABLE SIZES AND STRENGTHS
(Courtesy of Macwhyte Company)

Steel wire (piano)		Tinned aircraft cable			
Diameter, inches	Breaking strength, pounds	Cable diameter, inches	1 × 19	7 × 7	7 × 19
0.032	225	$\frac{1}{16}$	500	480	
0.047	460	$\frac{3}{32}$	1,100	920	
0.054	600	$\frac{1}{8}$	2,100	1,350	2,000
0.062	775	$\frac{5}{32}$	3,200	2,600	2,800
0.072	1,040	$\frac{3}{16}$	4,600	3,200	4,200
0.080	1,250	$\frac{7}{32}$	6,100	4,600	5,600
0.091	1,600	$\frac{1}{4}$	8,000	5,800	7,000
0.105	2,090	$\frac{9}{32}$	10,100	7,600	8,000
0.120	2,670	$\frac{5}{16}$	12,500	9,100	9,800

Flexible Cable and Extra-flexible Cable.—The construction of flexible cable is 7 × 7 and is used for control cables where the bends around pulleys are not sharp. This cable is not so flexible as 7 × 19, which is known as *extra-flexible cable*. Both flexible and extra-flexible cable are referred to as *control cable*. Both cables can be obtained in many sizes, but the

7×7 is obtainable in smaller than the 7×19. The extra-flexible cable is much better than the flexible and should be used where the bends around pulleys are sharp or numerous. These cables may be purchased in high carbon steel tinned, or stainless steel, preformed or nonpreformed. Table IV also gives standard sizes and strengths for these two cables. It will be noted from this table that the smallest extra-flexible cable is $\frac{1}{8}$ in. The wires for a cable any smaller would be so fine that they would wear out too quickly.

The CAA requires that all control cables larger than $\frac{1}{16}$ in. must be spliced either with the Army or the Navy five-tuck splice or with the Roebling roll splice. Directions for the Navy five-tuck splice are given below:

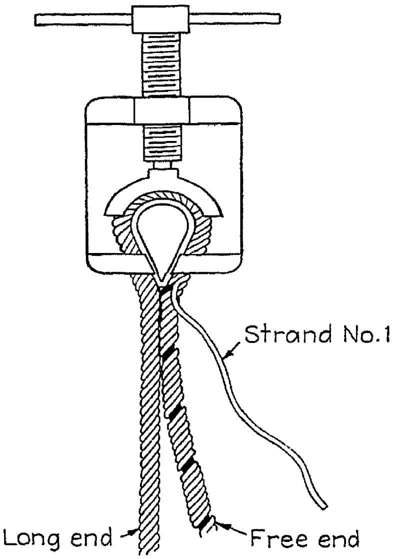


FIG. 163.—Unlaying strand No. 1.

To prevent the cable from unlaying after it has been cut, solder the portion to be cut. Wrap the cable around the thimble, and clamp it securely in a splicing clamp. The ends of the thimble should be bent up to allow for a tight splice (Fig. 163).

Insert the marlinspike under the free strand nearest the thimble, and unlay it by rotating the spike in a counterclockwise direction. This strand is No. 1F (Fig. 164).

Lift the top three strands on the stranding part of the cable with the marlinspike, and insert cable No. 1F (Fig. 164), pulling it tight with a pair of pliers.

Unlay free strand No. 2F, and insert it under the first two strands of the stranding part of the cable. Pull it snug with a pair of pliers.

The above procedure is repeated with each strand of the free end. Figure 164 shows how these strands are inserted to give the first tuck.

The strand to the left of the core strand, or strand No. 1F, is brought over strand No. 3L and under strand No. 2L, passing over the core strand. This is called *tucking over one and under one.*

Continue this process with strand No. 2F and all other strands in a clockwise direction. Pull all the strands snug with a pair of pliers. This completes the second tuck.

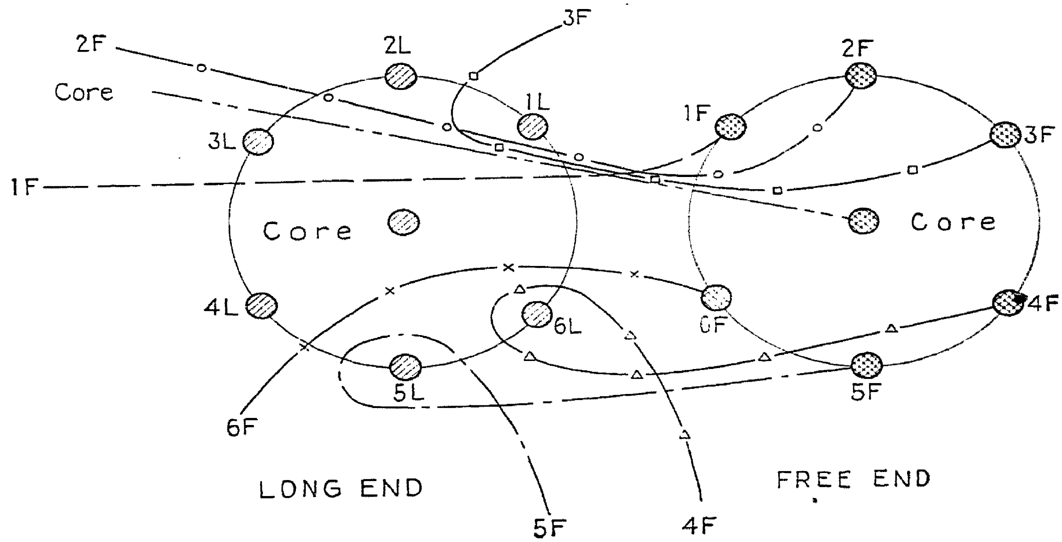


FIG. 164.—Cross-section of the first tuck in a cable splice. Dotted lines indicate path taken by the strands.

The third tuck is made in the same manner, beginning with the strand to the left of the core strand. After this tuck is made, cut off the remainder of the core strand.

Cut each strand in half, and repeat the over-and-under tuck. This is the fourth tuck.

Cut the strands in half again, and complete the fifth and final tuck. Cut off all excess material.

Place the completed splice on a hard wood block, and hammer with a rawhide mallet or brass hammer. Wrap the splice with linen cord, and shellac (Fig. 165).

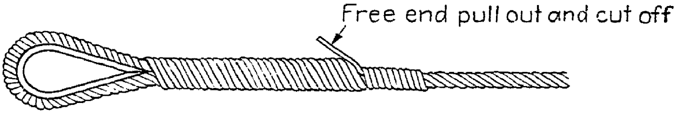


FIG. 165.—Wrapping the finished splice.

Thimbles, Bushings, Shackles, and Terminal Ends.—Cable terminal ends are always spliced around a thimble or bushing, usually the former. However, if the eye of the terminal passes

directly around a bolt, the bushing is more satisfactory. A thimble and a bushing are shown in Fig. 167.

Shackles are used to attach cables to plates. This end is sometimes called a *clevis end* (Fig. 167). In making the cable splice, it is necessary to insert the clevis, or shackle, in the thimble

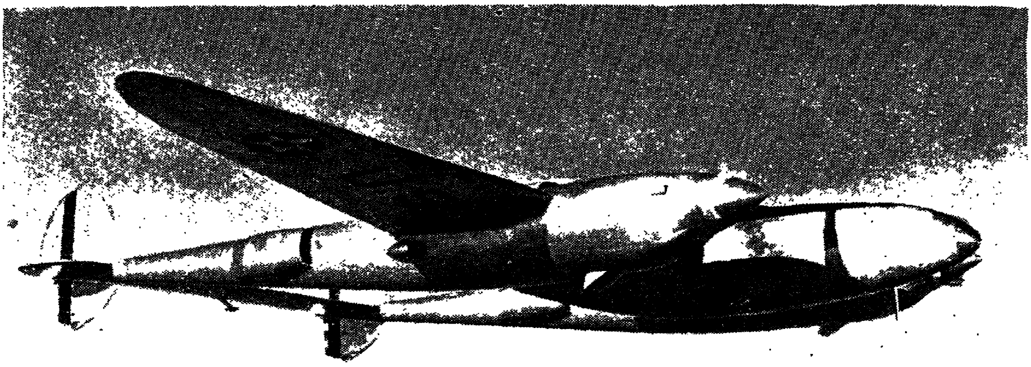


FIG. 166.—A Lockheed P-38 in flight. This ship relies on cables for operation of control surfaces and engine controls.

before wrapping the cable around the thimble. This is because most thimbles are too small to receive the shackle after the splice has been made.

In some instances where the temperature and load are not too great, a soldered type of terminal may be used (see Fig. 168).

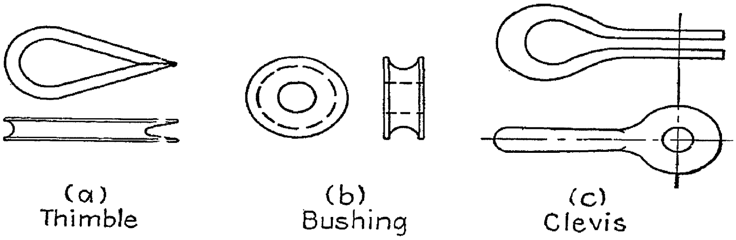


FIG. 167.

A standard five-tuck Navy splice cannot be replaced with this type of terminal without first receiving authority from the manufacturer and/or the CAA.

The swaged type of cable terminal is rapidly replacing the old form of splice with thimbles, etc. The use of swaged terminals

reduces costs by reducing labor. It also gives the desired terminal end without the need for a second link. However, the difficulty of threading these terminal ends through fair-leads and pulleys limited their use in the past. This difficulty has been overcome somewhat by the development of a portable swaging machine. Various types of swaged terminal are shown in Fig. 169. Cable stops also employ this method of attachment.

Swaging is done by hammering the wall of the terminal down tight on the cable inserted in the end of the terminal. This is done so effectively that the cable will break before it will pull out of the terminal.

The swaging machine has a large flywheel with small rollers inside the wheel. As the wheel rotates, these rollers drive a

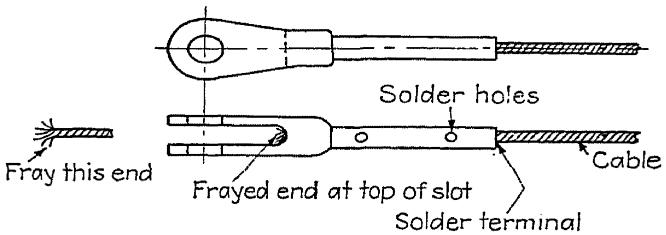


FIG. 168.—Solder terminal. Insert the free end of the cable in the terminal, fray it, and dip the whole terminal in a solder pot. After it has remained a sufficient time, remove and wipe off all excess solder with a rag.

hammer down on the terminal, squeezing the end tight against the cable.

Pulleys, Fair-leads, and Turnbuckles.—When control cables are stretched for long distances, they have a tendency to "whip" or rub on the near-by structure. This greatly reduces the life of the cable. To help prevent whipping, Formica fair-leads are placed at convenient locations. Small changes in direction of the cable can also be accomplished by the use of fair-leads. However, when this change in direction is great, pulleys must be used. Pulleys, also, are manufactured from Formica, a synthetic resin and fabric plastic. If the loads are great or if the temperature is high, aluminum pulleys are sometimes used. They may be equipped with roller, ball, or brass bearings (see Fig. 170).

Pulleys must be installed in such a manner that the cable cannot be pulled out of the groove, thus locking the controls. Two typical guards are shown in Fig. 171. The diameter of the pulley

is determined by the minimum radius of bend for the size of the cable used.

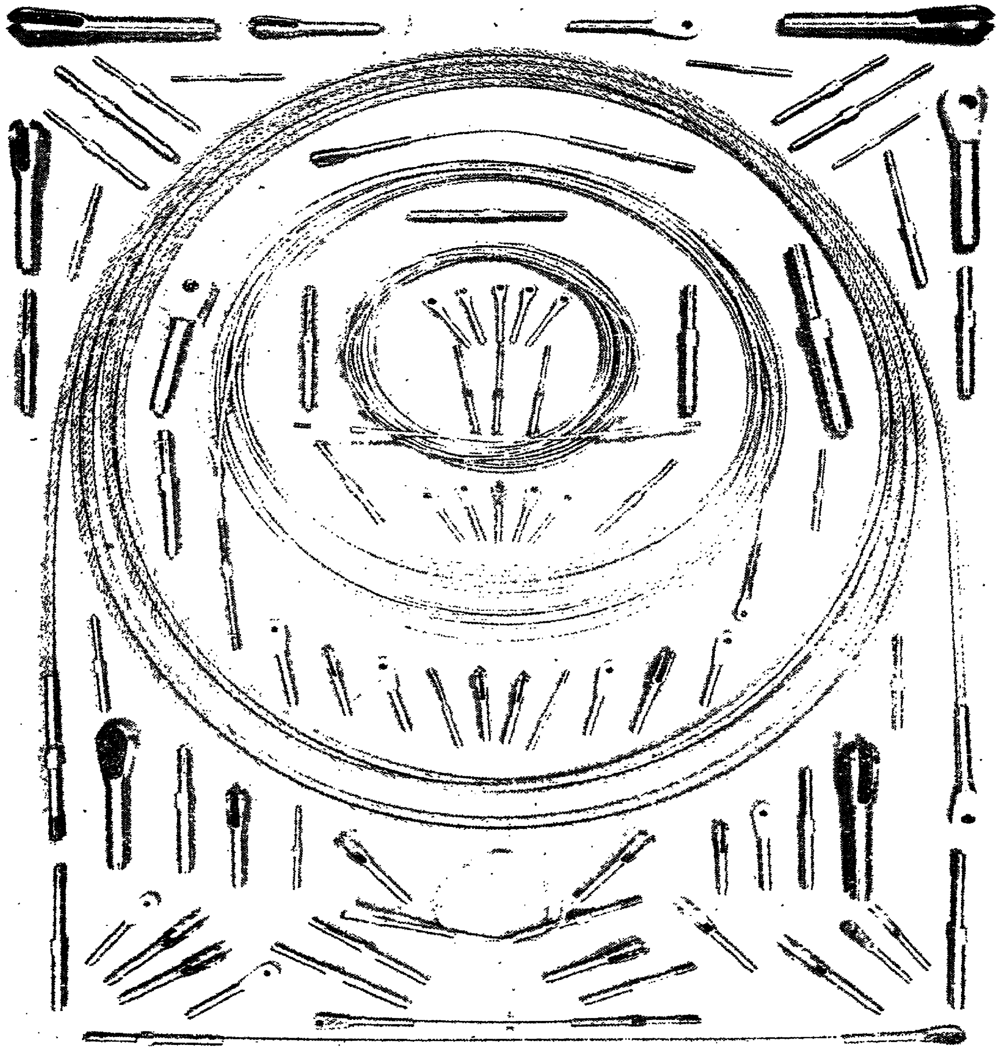


FIG. 169.—Various types and sizes of swaged cable terminals manufactured by Macwhyte Co.

Turnbuckles, composed of a barrel and two ends, are used to adjust wires and control cables. The barrel is made of either steel or brass, brass being the more common. One of the ends has right-hand threads, and the other left-hand threads. Three

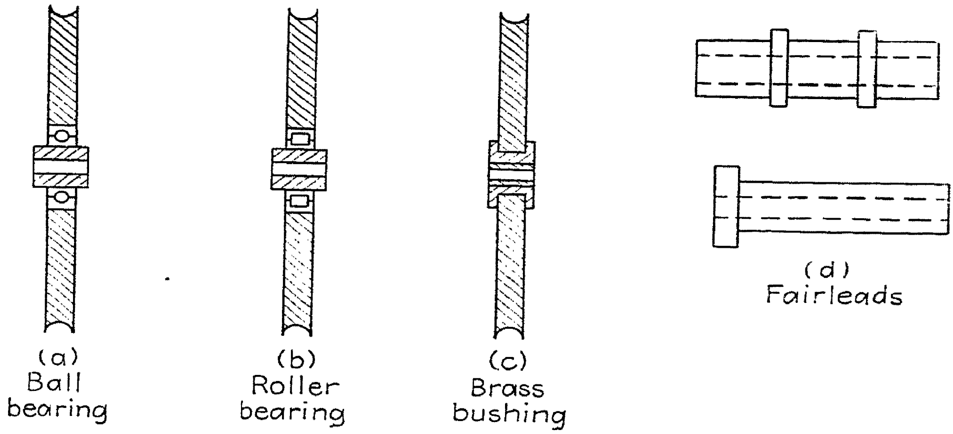


FIG. 170.

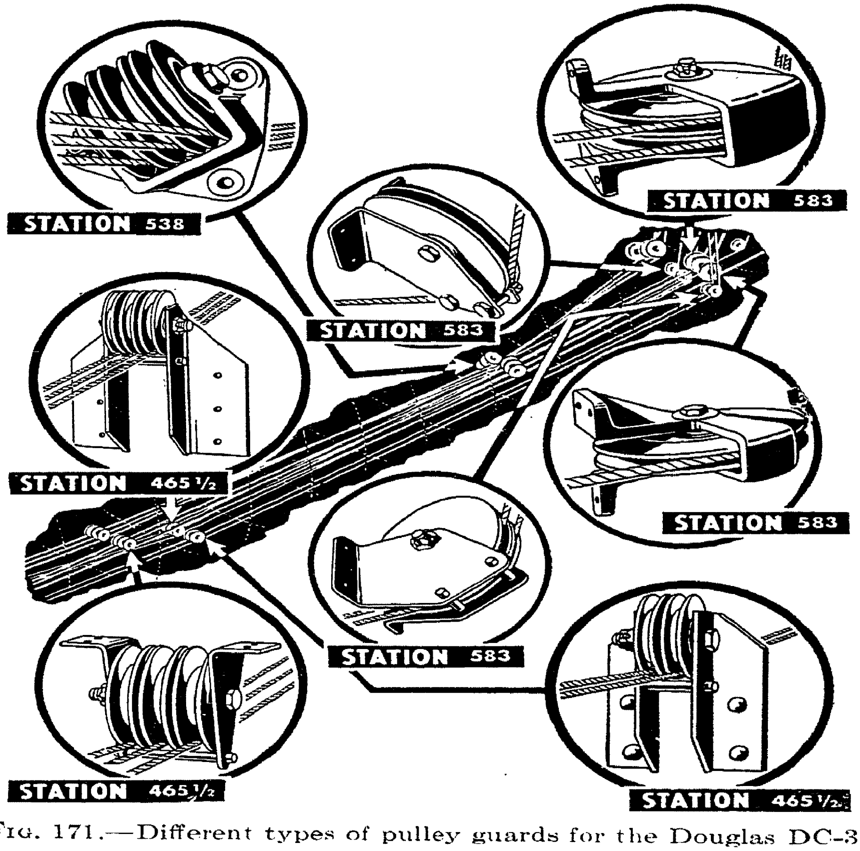


FIG. 171.—Different types of pulley guards for the Douglas DC-3.

types of end are available, the forked, the cable, and the pin or bolt ends (see Fig. 172). In most cases the forked or pin end has the right-hand threads.

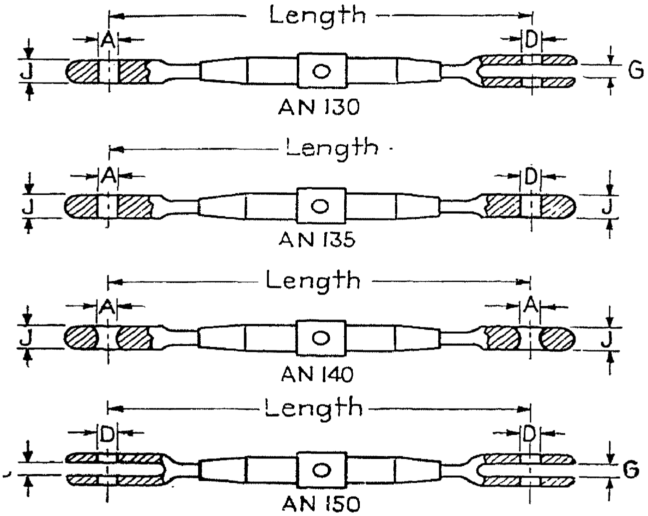


FIG. 172.—Turnbuckles. (*Courtesy of Macwhyte Co.*)

Table V gives the dimensions for the turnbuckles of Fig. 172. The AN number is the Army-Navy specification number, the dash number is the load in hundreds of pounds that the turn-

TABLE V.—STRENGTH AND SIZE OF TURNBUCKLES AN130, AN135, AN140, AND AN150

Dash No.	Strength, pounds	*L*, inches	*A*, inches	*D*, inches	*J*, inches	*G*, inches
-8S	800	4½	0.188	0.188	0.125	0.109
-16S	1,600	4½	0.219	0.188	0.188	0.150
-21S	2,100	4½	0.219	0.188	0.188	0.203
-32S	3,200	4½	0.281	0.250	0.219	0.203
-46S	4,600	4½	0.313	0.313	0.281	0.150
-16L	1,600	8	0.219	0.188	0.188	0.150
-21L	2,100	8	0.219	0.188	0.188	0.150
-32L	3,200	8	0.281	0.250	0.219	0.203
-46L	4,600	8	0.313	0.313	0.281	0.203
-61L	6,100	8	0.344	0.375	0.281	0.203
-80L	8,000	8	0.375	0.375	0.328	0.266
-125L	12,500	9	0.469	0.438	0.375	0.344
-175L	17,500	9½	0.563	0.500	0.469	0.406

buckle will withstand, and the letters S and L indicate whether the turnbuckle is long or short. Therefore, AN130 8S is a short turnbuckle, type 130, and will withstand 800 lb.

Tie Rods.—Tie rods are used to transmit tension loads or to give structure rigidity. They are now used mainly in the manufacture of biplanes and high-wing monoplanes in the low-price field. In the past they were also extensively used in fuselage construction. Tie rods may be obtained in the square

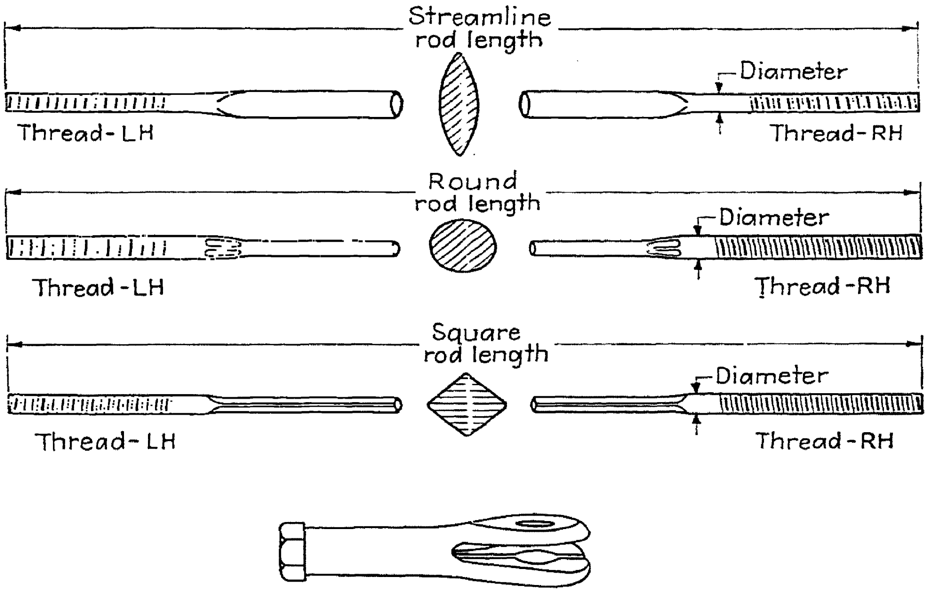


FIG. 173.—Tie rods and tie-rod ends. (*Courtesy of Macwhyte Co.*)

round, or streamlined form. The square and round rods are used for internal bracing of wing surfaces and tail assemblies; the streamlined rods are used for external bracing of wings and tail assemblies, as lift wires on a biplane.

These three forms of the tie rod are shown in Fig. 173. They can be obtained in any convenient length, manufactured of stainless steel or high carbon steel, cadmium plated. These rods are manufactured by rolling or drawing a round rod into the desired shape. A portion of both ends is left round for the threaded ends. If the rod is of the square or streamlined type, no means need be provided for rotating the rod for installation; however, on the round rod a small portion of the round shank

near the thread must be made square to permit the mechanic to rotate the rods. The tie rods have a right-hand thread on one end and a left-hand thread on the other, permitting the adjustment of the length. The ends are screwed into a right- and left-hand-thread tie-rod terminal, which is also shown in Fig. 173. Tie-rod terminals have forked ends. By attaching these terminals to the structure and rotating the rod, the desired length is obtained.

In assembling these rods, the ends should be greased to prevent rusting. When the desired length of the tie rod is obtained, the correct tension should also be obtained, so as not to overload the tie rod, causing it to fail under strain. If two tie rods are used together, *i.e.*, cross and diagonally, the correct tension must be obtained in both rods; otherwise, undue strain will be placed on one, causing it to fail. After the desired length and tension have been obtained, the tie-rod lock nut is tightened against the tie-rod terminal to prevent rotation.

TABLE VI.—STRENGTH AND SIZE OF TIE RODS
(Courtesy of Macwhyte Company)

Size and thread	Diameter at ends, inches	Strength, pounds cadmium-plated steel	Strength, pounds, stainless steel
No. 6-40	0.138	1,000	1,200
No. 10-32	0.190	2,100	2,500
$\frac{1}{4}$ in. -28	0.250	3,400	4,000
$\frac{5}{16}$ in. -24	0.3125	6,100	7,200
$\frac{3}{8}$ in. -24	0.375	8,000	9,600
$\frac{7}{16}$ in. -20	0.4375	11,500	13,700
$\frac{1}{2}$ in. -20	0.500	15,500	18,500

Inspection of Fig. 173 will show that there is a small hole in the terminal. In tightening the tie rod, it is necessary that the end of the tie rod pass this hole or the tie rod will not develop its full strength. That is, the strength of the tie rod is determined by the number of threads engaged, and should the end of the tie rod fail to pass this hole it will pull out of the terminal under maximum load. Therefore, after making all adjustments and determining the correct tension in the tie rod, a small piece of safety wire should be inserted in the hole. If the safety wire will

not pass through the tie rod to the opposite side, the end of the tie rod has passed this hole and the installation is correct.

On the diagonal rods a small piece of fiber and friction tape should be placed between the rods to prevent them from rubbing together. This may be held in place by brass safety wire.

Table VI lists the size of tie rods, diameter at the threaded ends, and strength of tie rods for stainless-steel and cadmium-plated steel rods. Table VII gives the strength and size of tie-rod terminals.

TABLE VII.—STRENGTH AND SIZE OF TIE-ROD TERMINALS
(Courtesy of Macwhyte Company)

Size and thread	Diameter at ends, inches	Strength, pounds, cadmium-plated steel	Strength, pounds, stainless steel
No. 6-40	0.138	1,000	1,200
No. 10-32	0.190	2,100	2,400
$\frac{1}{4}$ in. -28	0.250	3,400	4,200
$\frac{5}{16}$ in. -24	0.3125	6,100	6,900
$\frac{3}{8}$ in. -24	0.375	8,000	10,000
$\frac{7}{16}$ in. -20	0.4375	11,500	13,700
$\frac{1}{2}$ in. -20	0.500	15,500	18,500
$\frac{9}{16}$ in. -18	0.5625	20,200	24,000
$\frac{5}{8}$ in. -18	0.625	24,700	29,500

FABRIC AND METHOD OF APPLICATION

As stated earlier in this chapter, some airplanes still use fabric as a covering, particularly for the ailerons, elevators, and rudders. Because of its great strength and light weight, silk was used at first. However, today improved cotton fabrics have replaced silk.

Grade A mercerized cotton is the best fabric and is used on all ships requiring extra strength. It can be purchased in 36-, 42-, 60-, 69-, and 90-in. widths.

Light airplanes with small wing loading and slow speeds use a much lighter fabric called *light plane fabric.* Gliders require a still lighter fabric purchased under this name.

Fabric sheets are sewed together with a French fell seam (see Fig. 174). These seams run chordwise of the wing. On some ships the fabric is sewed, by machine, into an envelope that slips

over the wing or surface, requiring only one hand seam after installation. However, the mechanic in the field usually makes all seams on the wing by hand, except for the French fell seam.

Before the wing can be covered it must be painted with a dope-proof paint or varnish to prevent the fabric from sticking to the wing or surface. When this paint is dry, the fabric is placed

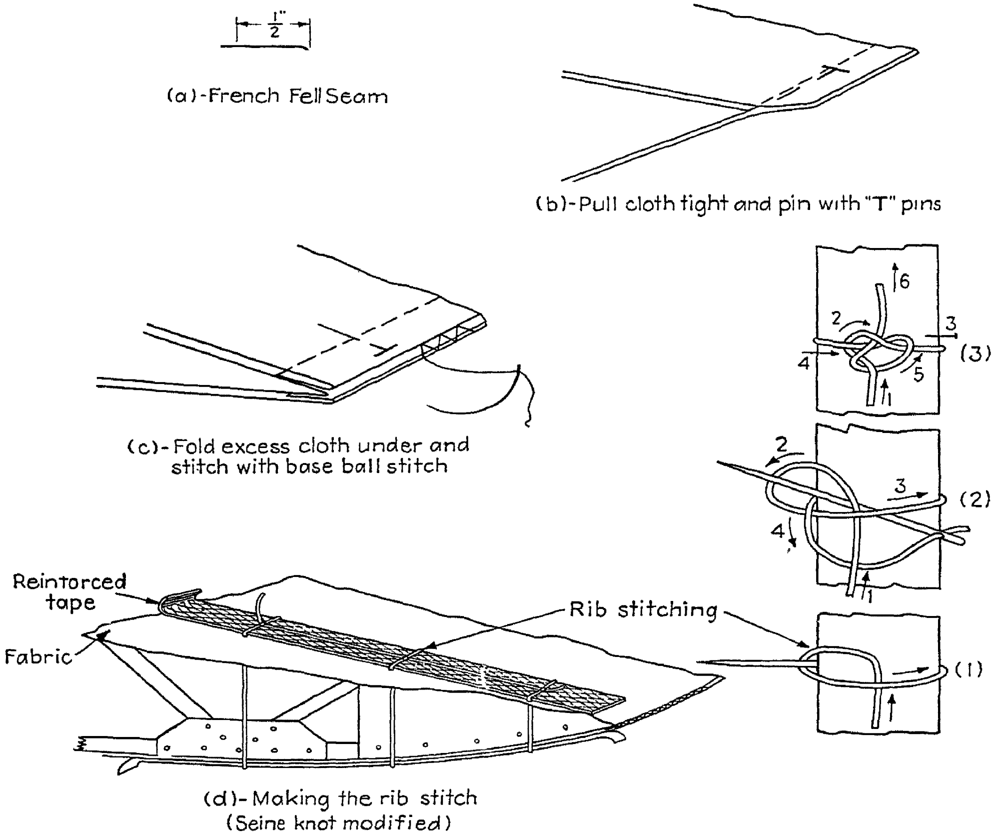


FIG. 174.

around the wing with the French fell seams parallel to the ribs and the final hand-sewn seams at the trailing edge and wing butt. The cloth is pulled tight by hand and pinned with T pins. After this, all excess material is removed, and the final seams are made with a baseball stitch.

Reinforcing tape, usually of a herringbone weave, is placed over the ribs to prevent the rib stitching from pulling through the

fabric. Over the reinforcing tape the rib stitches are made along each rib. Every stitch must be tied to prevent loss of fabric in case one stitch should fail. The CAA approved knot is the fish net knot, shown in Fig. 174.

Over all seams and edges, *plane tape* or *pinked-edge tape* is doped. This tape is made from the same material as the surface covering and can be purchased in widths of $1\frac{1}{4}$ to $3\frac{3}{4}$ in.

Miscellaneous Materials

Felt.—Felt is a material made from wool, hair, or fur under pressure and steam. It usually comes in wide rolls of varying thicknesses and grades. It is used for soundproofing, wear pads, etc.

Fiber.—Fiber, red or gray in color, is a soft material obtainable in sheet, tubing, or rod form. It is a nonconductor and is widely used as insulation and for fair-leads.

Floor Covering.—In order to improve the appearance of the airplane, some form of floor covering is generally used. The most popular coverings are wool rugs, cork-base linoleum, and pyramid rubber matting. The first two may be obtained in various colors to match the color scheme of the plane.

Fluids—Hydraulic.—(See chapter on Hydraulics.)

Glues and Cements.—Casein, Cascamite, and Weldwood are powder glues mixed with cold water to give a waterproof product. They may be used with either wood or fabric.

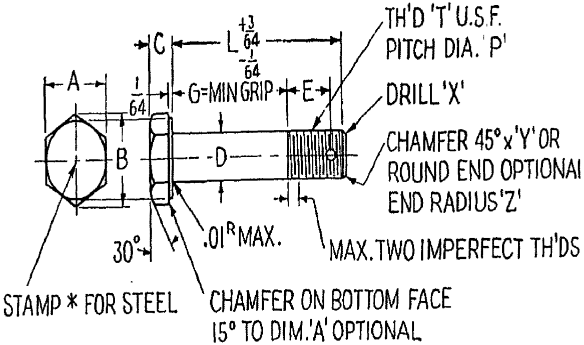
Rubber cement under the trade names of Plastikon and Voco-lock, manufactured by The B. F. Goodrich Company, is widely used to cement rubber and felt to wood and metal parts.

Hardware

Most standard parts of aircraft hardware are covered by the Army-Navy Specifications.

Bolts.—Most bolts used in the aircraft industry are standard and may be classified as plain, drilled, and clevis bolts. These bolts are made of nickel steel, S.A.E. 2330, cadmium plated to prevent rusting. Below, in Figs. 175 to 177, are given three tables for these bolts, containing their AN numbers.

Clamps.—Clamps are one of the most widely used small parts in aircraft construction and are available in many forms. Two types are shown in Fig. 178. They are used for hose connections,



Threads are national screw thread common medium fit, class 3, symbol NF-3. Steel-bolt sizes specified to be met after plating.

Part No.	A	B	C	D	E	P	T	X	Y	Z	L-G	Strength pull dia. single sh'r lb. for steel	Tensile strength at root dia. lb. for steel	Plain nut AN315		Castle nut AN310		Cotter pin AN380
														Dash No.	Max. grip	Dash No.	Max. grip	
AN3	3/8	7/16	1/8	0.189 +0000 −0025	1/4	0.1697 +0000 −0015	No. 10-32	No. 50(0.070)	1/32	3/16	3/8	2026	2190	− 3R	G + 1/8	− 3	G + 7/64	−2-2
AN4	7/16	1/2	5/32	0.249 +000 −003	9/32	0.2268 +0000 −0022	1/4-28	No. 48(0.076)	1/32	1/4	7/16	3681	4070	− 4R	G + 1/8	− 4	G + 1/8	−2-2
AN5	1/2	37/64	3/16	0.3115 +000 −003	21/64	0.2854 +0000 −0024	5/16-24	No. 48(0.076)	3/64	5/16	7/16	5751	6560	− 5R	G + 3/16	− 5	G + 1/8	−2-2
AN6	9/16	21/32	7/32	0.374 +000 −000	13/32	0.3479 +0000 −0024	3/8-24	No. 36(0.106)	3/64	3/8	9/16	8287	10100	− 6R	G + 1/4	− 6	G + 9/64	−3-3
AN7	5/8	23/32	1/4	0.4365 +0000 −0035	29/64	0.4050 +0000 −0026	7/16-20	No. 36(0.106)	3/64	7/16	9/16	11272	13620	− 7R	G + 7/32	− 7	G + 9/64	−3-3
AN8	3/4	7/8	9/32	0.499 +0000 −0035	9/16	0.4675 +0000 −0026	1/2-20	No. 36(0.106)	3/64	1/2	11/16	14722	18580	− 8R	G + 5/16	− 8	G + 5/32	−3-3

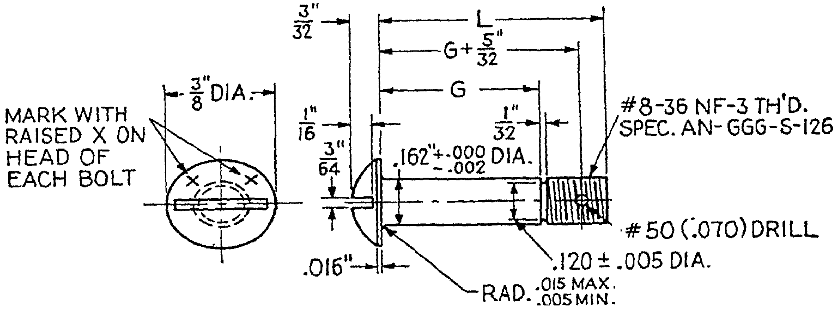
Part No.	A	B	C	D	E	P	T	X	Y	Z	L-G	Strength pull dia. single sh'r lb. for steel	Tensile strength at root dia. lb. for steel	Plain nut AN315		Castle nut AN310		Cotter pin AN380
														Dash No.	Max. grip	Dash No.	Max. grip	
AN9	$\frac{7}{8}$	$1\frac{1}{64}$	$\frac{5}{16}$	$0.5615\ {}^{+000}_{-004}$	$\frac{39}{64}$	$0.5264\ {}^{+0000}_{-0030}$	$\frac{9}{16}$-18	No. 28(0.141)	$\frac{3}{64}$	$\frac{9}{16}$	$\frac{3}{4}$	18637	23600	− 9R	$G + \frac{5}{16}$	− 9	$G + \frac{5}{32}$	−4-4
AN10	$\frac{15}{16}$	$1\frac{3}{32}$	$\frac{11}{32}$	$0.624\ {}^{+000}_{-004}$	$\frac{11}{16}$	$0.5889\ {}^{+0000}_{-0030}$	$\frac{5}{8}$-18	No. 28(0.141)	$\frac{3}{64}$	$\frac{5}{8}$	$\frac{13}{16}$	23010	30000	−10R	$G + \frac{11}{32}$	−10	$G + \frac{5}{32}$	−4-4
AN12	$1\frac{1}{16}$	$1\frac{15}{64}$	$\frac{13}{32}$	$0.749\ {}^{+0000}_{-0045}$	$\frac{13}{16}$	$0.7094\ {}^{+0000}_{-0032}$	$\frac{3}{4}$-16	No. 28(0.141)	$\frac{3}{64}$	$\frac{3}{4}$	$\frac{15}{16}$	33135	43900	−12R	$G + \frac{3}{8}$	−12	$G + \frac{3}{16}$	−4-5
AN14	$1\frac{1}{4}$	$1\frac{7}{16}$	$\frac{15}{32}$	$0.874\ {}^{+000}_{-005}$	$\frac{29}{32}$	$0.8286\ {}^{+0000}_{-0036}$	$\frac{7}{8}$-14	No. 28(0.141)	$\frac{3}{64}$	$\frac{7}{8}$	$1\frac{1}{16}$	45097	60065	−14R	$G + \frac{3}{8}$	−14	$G + \frac{3}{16}$	−4-5
AN16	$1\frac{7}{16}$	$1\frac{21}{32}$	$\frac{17}{32}$	$0.999\ {}^{+0000}_{-0055}$	1	$0.9536\ {}^{+0000}_{-0036}$	1-14	No. 28(0.141)	$\frac{3}{64}$	1	$1\frac{1}{8}$	58905	80810	−16R	$G + \frac{3}{8}$	−16	$G + \frac{3}{16}$	−4-6

Part No.	AN3	AN4	AN5	AN6	AN7	AN8	AN9	AN10	AN12	AN14	AN16
Clearance drill	No. 10(0.194)	E(0.250)	$\frac{5}{16}$(0.3125)	$\frac{3}{8}$(0.375)	$\frac{7}{16}$(0.4375)	$\frac{1}{2}$(0.500)	$\frac{9}{16}$(0.5625)	$\frac{5}{8}$(0.625)	$\frac{3}{4}$(0.750)	$\frac{7}{8}$(0.875)	1(1.00)
Tap drill	No. 22(0.157)	No. 3(0.213)	I(0.272)	Q(0.332)	W(0.386)	$\frac{29}{64}$(0.453)	(0.5062)	(0.5709)	$\frac{11}{16}$(0.6875)	$\frac{51}{64}$(0.797)	(0.9252)

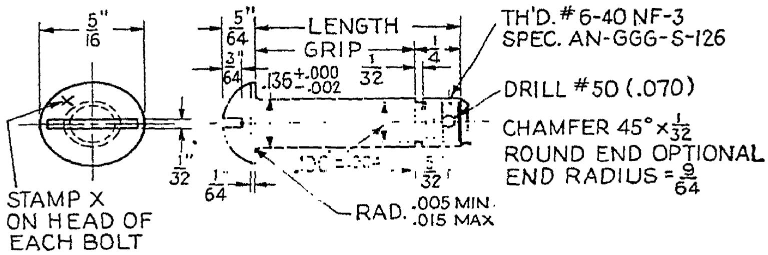
Code: AN3-4-Bolt steel $\frac{3}{16}$ dia by $\frac{4}{8}$ long. AN310-3-Steel castle nut for $\frac{3}{16}$ bolt. Example for determination of length and dash number: Required $\frac{3}{4}$ steel bolt with castle nut and grip of $2\frac{5}{16}$. Under AN310-12 Maximum grip $= G + \frac{3}{16} = 2\frac{5}{16}$; then minimum grip $= G = 2\frac{5}{16} - \frac{3}{16} = 2\frac{1}{8}$. L-G for AN12 $= \frac{15}{16}$, therefore minimum L. $= 2\frac{1}{8} + \frac{15}{16} = 3\frac{1}{16}$. As bolt lengths are in eighths of inches the nearest larger size is used, which is $3\frac{1}{8}$. The bolt will be AN12-31, the castle nut AN310-12, and the cotter pin AN380-4-5. Use same cotters for both steel and dural bolts. Dural bolts are AC 57-152-4 (See standard parts book for strength values). Steel bolts are AC 57-107-17 (S.A.E. 2330).

FIG. 175.—AN3 to AN16 hex-head bolt. (*Taken from Douglas Drafting Manual.*)

to attach accessories to the structure, and to hold conduit, or lines, in place. They are manufactured from aluminum alloy and steel, cadmium plated.



AN22



AN21

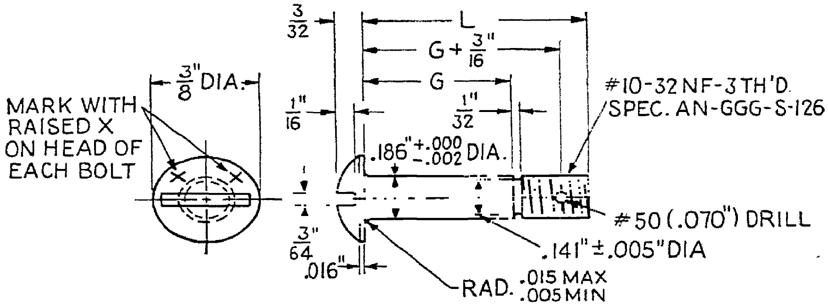
Dash No.	Length	Grip	Dash No.	Length	Grip	Dash No.	Length	Grip	Dash No.	Length	Grip
5	$\frac{5}{16}$	$\frac{1}{16}$	12	$\frac{3}{4}$	$\frac{1}{2}$	19	$1\frac{3}{16}$	$\frac{15}{16}$	26	$1\frac{5}{8}$	$1\frac{3}{8}$
6	$\frac{3}{8}$	$\frac{1}{8}$	13	$\frac{13}{16}$	$\frac{9}{16}$	20	$1\frac{1}{4}$	1	27	$1\frac{11}{16}$	$1\frac{7}{16}$
7	$\frac{7}{16}$	$\frac{3}{16}$	14	$\frac{7}{8}$	$\frac{5}{8}$	21	$1\frac{5}{16}$	$1\frac{1}{16}$	28	$1\frac{3}{4}$	$1\frac{1}{2}$
8	$\frac{1}{2}$	$\frac{1}{4}$	15	$\frac{15}{16}$	$\frac{11}{16}$	22	$1\frac{3}{8}$	$1\frac{1}{8}$	29	$1\frac{13}{16}$	$1\frac{9}{16}$
9	$\frac{9}{16}$	$\frac{5}{16}$	16	1	$\frac{3}{4}$	23	$1\frac{7}{16}$	$1\frac{3}{16}$	30	$1\frac{7}{8}$	$1\frac{5}{8}$
10	$\frac{5}{8}$	$\frac{3}{8}$	17	$1\frac{1}{16}$	$\frac{13}{16}$	24	$1\frac{1}{2}$	$1\frac{1}{4}$	31	$1\frac{15}{16}$	$1\frac{11}{16}$
11	$\frac{11}{16}$	$\frac{7}{16}$	18	$1\frac{1}{8}$	$\frac{7}{8}$	25	$1\frac{9}{16}$	$1\frac{5}{16}$	32	2	$1\frac{3}{4}$

Add "A" after dash number for bolt without cotter-pin hole.
Example of part No.: AN21-8
AN21-8A
Position of slot in head relative to cotter-pin hole is optional.

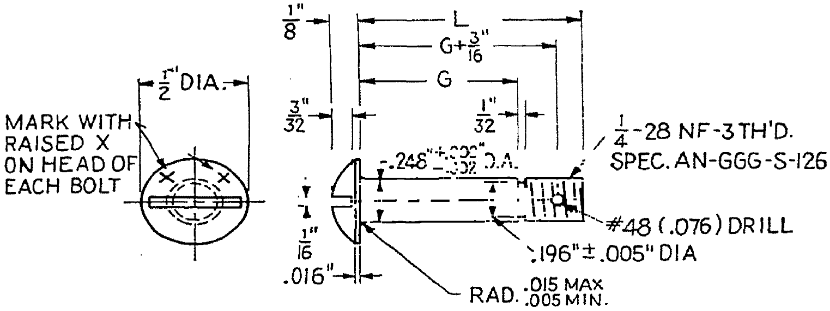
FIG. 176.—AN21 (6-40) and AN22 (8-36) clevis bolts.

Clevis Pins.—Clevis pins are used in control systems to attach control cables, rod ends, etc. Because they do not require a nut but are held in place by cotter keys only, they make for easy installation. Figure 179 shows a $\frac{3}{16}$-in. clevis pin, the most popular size used.

Cotter Pins.—Cotter pins are used as a safety device for drilled aircraft bolts and clevis pins. They may be brass or



AN34



AN43

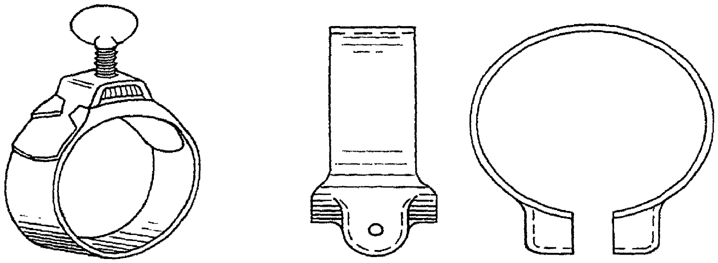
Dash No.	Length	Grip	Dash No.	Length	Grip	Dash No.	Length	Grip	Dash No.	Length	Grip
8	$\frac{1}{2}$	$\frac{3}{16}$	20	$1\frac{1}{4}$	$\frac{15}{16}$	32	2	$1\frac{11}{16}$	56	$3\frac{1}{2}$	$3\frac{3}{16}$
9	$\frac{9}{16}$	$\frac{1}{4}$	21	$1\frac{5}{16}$	1	34	$2\frac{1}{8}$	$1\frac{13}{16}$	58	$3\frac{5}{8}$	$3\frac{5}{16}$
10	$\frac{5}{8}$	$\frac{5}{16}$	22	$1\frac{3}{8}$	$1\frac{1}{16}$	36	$2\frac{1}{4}$	$1\frac{15}{16}$	60	$3\frac{3}{4}$	$3\frac{7}{16}$
11	$\frac{11}{16}$	$\frac{3}{8}$	23	1 [illegible]/16	$1\frac{1}{8}$	38	$2\frac{3}{8}$	$2\frac{1}{16}$	62	$3\frac{7}{8}$	$3\frac{9}{16}$
12	$\frac{3}{4}$	$\frac{7}{16}$	24	$1\frac{1}{2}$	$1\frac{3}{16}$	40	$2\frac{1}{2}$	$2\frac{3}{16}$	64	4	$3\frac{11}{16}$
13	$\frac{13}{16}$	$\frac{1}{2}$	25	$1\frac{9}{16}$	$1\frac{1}{4}$	42	$2\frac{5}{8}$	$2\frac{5}{16}$	66	$4\frac{1}{8}$	$3\frac{13}{16}$
14	$\frac{7}{8}$	$\frac{9}{16}$	26	$1\frac{5}{8}$	$1\frac{5}{16}$	44	$2\frac{3}{4}$	2 [illegible]/16	68	$4\frac{1}{4}$	$3\frac{15}{16}$
15	$\frac{15}{16}$	$\frac{5}{8}$	27	$1\frac{11}{16}$	$1\frac{3}{8}$	46	$2\frac{7}{8}$	$2\frac{9}{16}$	70	$4\frac{3}{8}$	$4\frac{1}{16}$
16	1	$\frac{11}{16}$	28	$1\frac{3}{4}$	$1\frac{7}{16}$	48	3	$2\frac{11}{16}$	72	$4\frac{1}{2}$	$4\frac{3}{16}$
17	$1\frac{1}{16}$	$\frac{3}{4}$	29	$1\frac{13}{16}$	$1\frac{1}{2}$	50	$3\frac{1}{8}$	$2\frac{13}{16}$			
18	$1\frac{1}{8}$	$\frac{13}{16}$	30	$1\frac{7}{8}$	$1\frac{9}{16}$	52	$3\frac{1}{4}$	$2\frac{15}{16}$			
19	$1\frac{3}{16}$	$\frac{7}{8}$	31	1 [illegible]	$1\frac{5}{8}$	54	$3\frac{3}{8}$	$3\frac{1}{16}$			

Add "A" after dash number for bolt without cotter-pin hole.
Example of part number:
AN24-14 = $\frac{1}{4}$ bolt, $\frac{7}{8}$ long, steel with cotter pin hole.
AN24-14A = $\frac{1}{4}$ bolt, $\frac{7}{8}$ long, steel without cotter pin hole.
Position of slot in head is relative to cotter-pin hole.

FIG. 177.—AN23 (10-32) and AN24 ($\frac{1}{4}$-28) clevis bolts.

steel, cadmium plated. When they are used with castle nuts, one leg of the pin is bent up over the end of the bolt, and the other leg is bent down along the flat side of the nut. The cotter

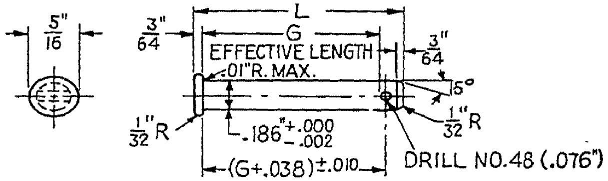
pin should be tapped tight with a small hammer, after all excess materials have been cut off. When it is used with a clevis pin, both legs are bent back over the pin.



(a) (b)

FIG. 178.—Two forms of aircraft clamps.

Dzus Fasteners.—Dzus fasteners, manufactured by the Dzus Fastener Company, are one of the most satisfactory fasteners. They can be purchased with brazier heads or flush heads and are



Dash No.	Grip	Length	Dash No.	Grip	Length	Dash No.	Grip	Length	Dash No.	Grip	Length
7	$\frac{7}{32}$	$\frac{25}{64}$	23	$\frac{23}{32}$	$\frac{57}{64}$	39	$1\frac{7}{32}$	$1\frac{25}{64}$	55	$1\frac{23}{32}$	$1\frac{57}{64}$
9	$\frac{9}{32}$	$\frac{29}{64}$	25	$\frac{25}{32}$	$\frac{61}{64}$	41	$1\frac{9}{32}$	$1\frac{29}{64}$	57	$1\frac{25}{32}$	$1\frac{61}{64}$
11	$\frac{11}{32}$	$\frac{33}{64}$	27	$\frac{27}{32}$	$1\frac{1}{64}$	43	$1\frac{11}{32}$	$1\frac{33}{64}$	59	$1\frac{27}{32}$	$2\frac{1}{64}$
13	$\frac{13}{32}$	$\frac{37}{64}$	29	$\frac{29}{32}$	$1\frac{5}{64}$	45	$1\frac{13}{32}$	$1\frac{37}{64}$	61	$1\frac{29}{32}$	$2\frac{5}{64}$
15	$\frac{15}{32}$	$\frac{41}{64}$	31	$\frac{31}{32}$	$1\frac{9}{64}$	47	$1\frac{15}{32}$	$1\frac{41}{64}$	63	$1\frac{31}{32}$	$2\frac{9}{64}$
17	$\frac{17}{32}$	$\frac{45}{64}$	33	$1\frac{1}{32}$	$1\frac{13}{64}$	49	$1\frac{17}{32}$	$1\frac{45}{64}$			
19	$\frac{19}{32}$	$\frac{49}{64}$	35	$1\frac{3}{32}$	$1\frac{17}{64}$	51	$1\frac{19}{32}$	$1\frac{49}{64}$			
21	$\frac{21}{32}$	$\frac{53}{64}$	37	$1\frac{5}{32}$	$1\frac{21}{64}$	53	$1\frac{21}{32}$	$1\frac{53}{64}$			

Code: AN393-9 = pin — flat-headed $\frac{3}{16}$ diameter by $\frac{9}{32}$ length.
Minimum strength in single shear: 2070 lb. Use cotter pin AN380-2-2. Material: 57-107-17 steel. Heat treat: 125,000 lb. p.s.i. T.S. Manufacturing specifications: 29-19, Limits of dimensions: ± 0.010 unless otherwise specified.

FIG. 179.—AN393 $\frac{3}{16}$-in. clevis pin.

extensively used for cowling, inspection doors, and any item that may require quick access (Fig. 180).

Nuts.—Many different types of aircraft nut are used. The most common are castle, shear, plain, check, and fiber nuts.

Castle nuts are used with drilled bolts when a positive lock is desired. This lock may be made with either brass or steel cotter pins or safety wire.

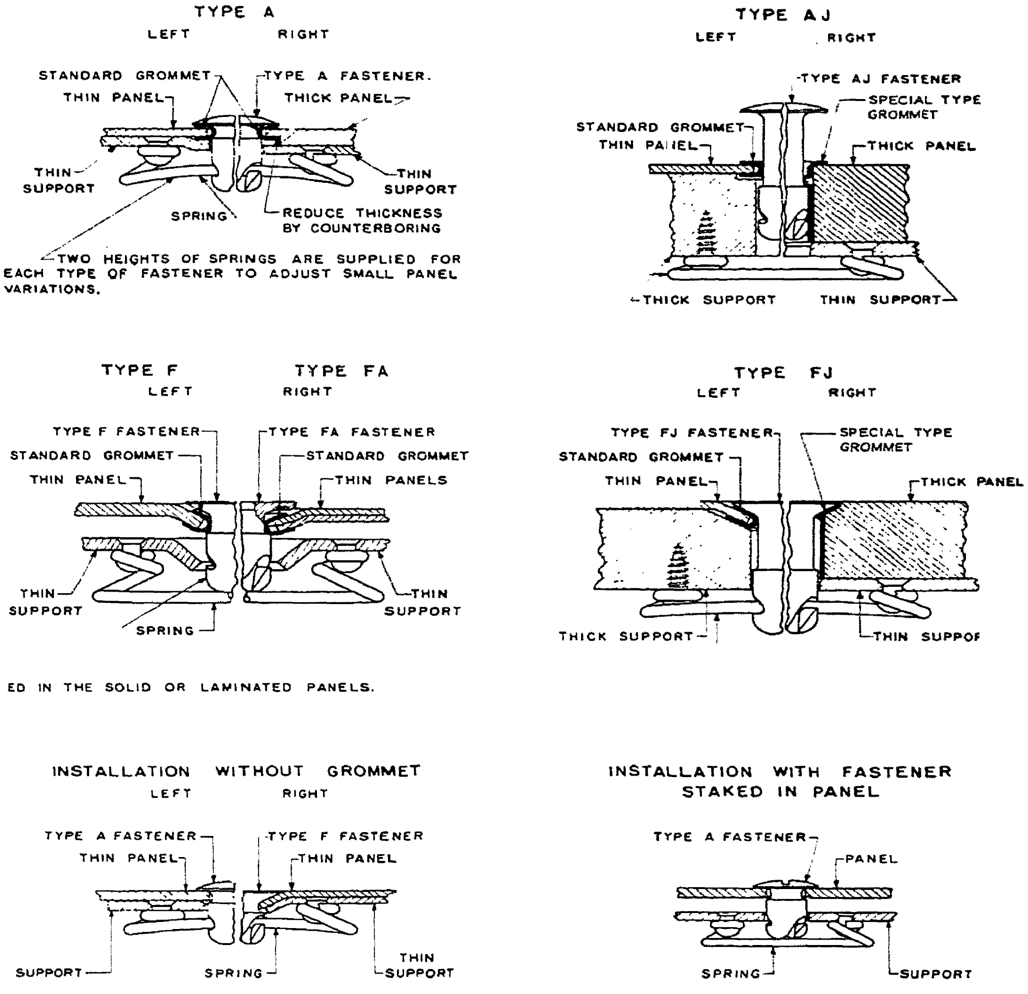
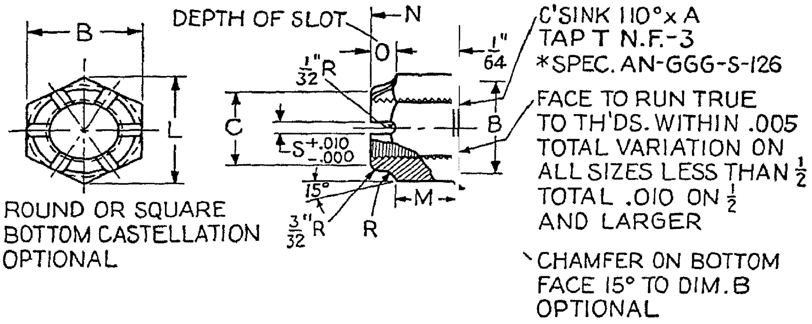


FIG. 180.—Several forms of Dzus fasteners used to attach cowling and small panels.

The shear nut has fewer threads than the castle nut. It is used in small spaces where the bolt is subjected to shear only. This nut is shown in Fig. 182.

The plain nuts are used in connection with plain and lock washers. They are sometimes used with check nuts on parts

requiring frequent adjustments. The AN data for the plain nut are given in Fig. 183.



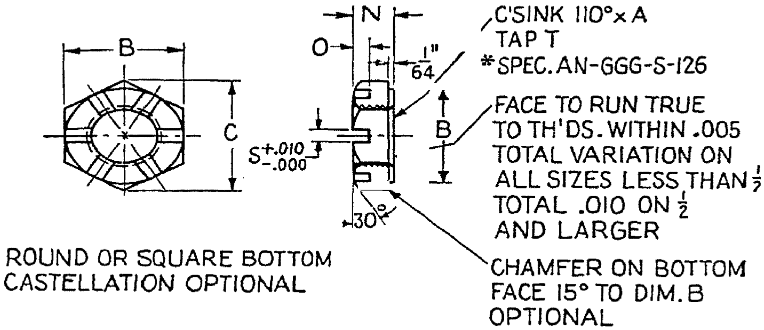
Dash number		Tap No., *T*	*A*	*B*	*N*	*M*	*O*	*S*	*C*	*R*	*L*
Steel	Aluminum alloy										
3	D3	10-32	190	3/8 + 0.002 − 0.010	1/4	0.110	9/64	5/64	0.221	3/32	7/16
4	D4	1/4-28	1/4	7/16 + 0.002 − 0.010	9/32	0.125	5/32	5/64	0.312	3/32	1/2
5	D5	5/16-24	5/16	1/2 + 0.002 − 0.010	21/64	0.172	5/32	5/64	0.375	3/32	37/64
6	D6	3/8-24	3/8	9/16 + 0.0025 − 0.010	13/32	0.218	3/16	1/8	0.437	3/32	21/32
7	D7	7/16-20	7/16	5/8 + 0.0025 − 0.010	29/64	0.265	3/16	1/8	0.532	3/32	23/32
8	D8	1/2-20	1/2	3/4 + 0.0025 − 0.010	9/16	0.359	13/64	1/8	0.594	1/8	7/8
9	D9	9/16-18	9/16	7/8 + 0.0025 − 0.010	39/64	0.390	7/32	5/32	0.657	5/32	1 1/64
10	D10	5/8-18	5/8	1 + 0.0025 − 0.010	11/16	0.468	7/32	5/32	0.719	5/32	1 5/32
12	D12	3/4-16	3/4	1 1/8 + 0.003 − 0.010	13/16	0.562	1/4	5/32	0.875	3/16	1 19/64
14	D14	7/8-14	7/8	1 5/16 + 0.003 − 0.010	29/32	0.656	1/4	5/32	1.000	3/16	1 33/64
16	D16	1-14	1	1 1/2 + 0.003 − 0.010	1	0.750	1/4	5/32	1.125	5/16	1 47/64

Example of part number—AN310-4
AN310D4

* Specification 29-26. Limits on dimensions ±0.010 unless otherwise specified.

FIG. 181.—AN310 aircraft castle nut.

Fiber nuts may ordinarily be used in place of the castle nut. However, below are given some of the restrictions on the use of

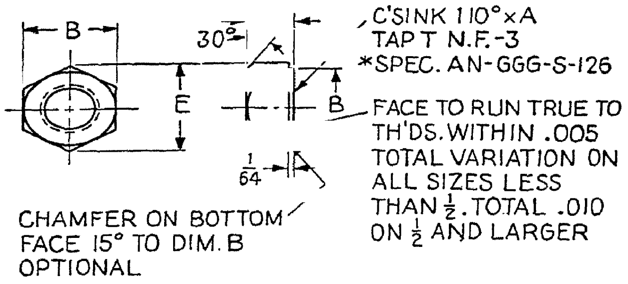


Dash number		Tap No. *T*	*A*	*B*	*N*	*S*	*O*	*C*
Steel	Aluminum alloy							
1	D1	6-40	0.138	$\frac{5}{16}\,{}^{+0.002}_{-0.010}$	$\frac{5}{32}$	$\frac{5}{64}$	$\frac{5}{64}$	$\frac{23}{64}$
2	D2	8-36 NF-3	0.164	$\frac{11}{32}\,{}^{+0.002}_{-0.010}$	$\frac{5}{32}$	$\frac{5}{64}$	$\frac{5}{64}$	$\frac{25}{64}$
3	D3	10-32 NF-3	0.190	$\frac{3}{8}\,{}^{+0.002}_{-0.010}$	$\frac{3}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{16}$
4	D4	$\frac{1}{4}$-28 NF-3	$\frac{1}{4}$	$\frac{7}{16}\,{}^{+0.002}_{-0.010}$	$\frac{3}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{1}{2}$
5	D5	$\frac{5}{16}$-24 NF-3	$\frac{5}{16}$	$\frac{1}{2}\,{}^{+0.002}_{-0.010}$	$\frac{3}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{37}{64}$
6	D6	$\frac{3}{8}$-24 NF-3	$\frac{3}{8}$	$\frac{9}{16}\,{}^{+0.0025}_{-0.010}$	$\frac{7}{32}$	$\frac{1}{8}$	$\frac{7}{64}$	$\frac{21}{32}$
7	D7	$\frac{7}{16}$-20 NF-3	$\frac{7}{16}$	$\frac{5}{8}\,{}^{+0.0025}_{-0.010}$	$\frac{7}{32}$	$\frac{1}{8}$	$\frac{7}{64}$	$\frac{23}{32}$
8	D8	$\frac{1}{2}$-20 NF-3	$\frac{1}{2}$	$\frac{3}{4}\,{}^{+0.0025}_{-0.010}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{7}{64}$	$\frac{7}{8}$
9	D9	$\frac{9}{16}$-18 NF-3	$\frac{9}{16}$	$\frac{7}{8}\,{}^{+0.0025}_{-0.010}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$1\frac{1}{64}$
10	D10	$\frac{5}{8}$-18 NF-3	$\frac{5}{8}$	$1\,{}^{+0.0025}_{-0.010}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$1\frac{5}{32}$
12	D12	$\frac{3}{4}$-16 NF-3	$\frac{3}{4}$	$1\frac{1}{8}\,{}^{+0.003}_{-0.010}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{1}{8}$	$1\frac{19}{64}$
14	D14	$\frac{7}{8}$-14 NF-3	$\frac{7}{8}$	$1\frac{5}{16}\,{}^{+0.003}_{-0.010}$	$\frac{7}{16}$	$\frac{5}{32}$	$\frac{1}{8}$	$1\frac{33}{64}$
16	D16	1-14 NF-3	1	$1\frac{1}{2}\,{}^{+0.003}_{-0.010}$	$\frac{1}{2}$	$\frac{5}{32}$	$\frac{1}{8}$	$1\frac{47}{64}$
20	D20	$1\frac{1}{4}$-12 N-3	$1\frac{1}{4}$	$1\frac{7}{8}\,{}^{+0.003}_{-0.010}$	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$2\frac{11}{64}$

Example of part number: AN320-4
AN320D4

* Specification 29-26. Limits on dimensions ± 0.010 unless otherwise specified.

FIG. 182.—AN320 aircraft shear nut.



Dash number				Tap No., *T*	*A*	*B*	*N*	*E*
Steel		Aluminum alloy						
L.H.	R.H.	L.H.	R.H.					
640L	640R	D640L	D640R	6-40	0.138	$\frac{5}{16}$ $^{+0.002}_{-0.010}$	$\frac{7}{64}$	$\frac{23}{64}$
3L	3R	D3L	D3R	10-32	0.190	$\frac{3}{8}$ $^{+0.002}_{-0.010}$	$\frac{9}{64}$	$\frac{7}{16}$
4L	4R	D4L	D4R	$\frac{1}{4}$-28	$\frac{1}{4}$	$\frac{7}{16}$ $^{+0.002}_{-0.010}$	$\frac{3}{16}$	$\frac{1}{2}$
5L	5R	D5L	D5R	$\frac{5}{16}$-24	$\frac{5}{16}$	$\frac{1}{2}$ $^{+0.002}_{-0.010}$	$\frac{15}{64}$	$\frac{37}{64}$
6L	6R	D6L	D6R	$\frac{3}{8}$-24	$\frac{3}{8}$	$\frac{9}{16}$ $^{+0.0025}_{-0.010}$	$\frac{9}{32}$	$\frac{21}{32}$
7L	7R	D7L	D7R	$\frac{7}{16}$-20	$\frac{7}{16}$	$\frac{5}{8}$ $^{+0.0025}_{-0.010}$	$\frac{21}{64}$	$\frac{23}{32}$
8L	8R	D8L	D8R	$\frac{1}{2}$-20	$\frac{1}{2}$	$\frac{3}{4}$ $^{+0.0025}_{-0.010}$	$\frac{3}{8}$	$\frac{7}{8}$
9L	9R	D9L	D9R	$\frac{9}{16}$-18	$\frac{9}{16}$	$\frac{7}{8}$ $^{+0.0025}_{-0.010}$	$\frac{27}{64}$	$1\frac{1}{64}$
10L	10R	D10L	D10R	$\frac{5}{8}$-18	$\frac{5}{8}$	1 $^{+0.0025}_{-0.010}$	$\frac{15}{32}$	$1\frac{5}{32}$
12L	12R	D12L	D12R	$\frac{3}{4}$-16	$\frac{3}{4}$	$1\frac{1}{8}$ $^{+0.003}_{-0.010}$	$\frac{9}{16}$	$1\frac{19}{64}$
14L	14R	D14L	D14R	$\frac{7}{8}$-14	$\frac{7}{8}$	$1\frac{5}{16}$ $^{+0.003}_{-0.010}$	$\frac{21}{32}$	$1\frac{33}{64}$
16L	16R	D16L	D16R	1-14	1	$1\frac{1}{2}$ $^{+0.003}_{-0.010}$	$\frac{3}{4}$	$1\frac{47}{64}$

Example of part number: { AN315-4L / AN315D4L

* Specification 29-26. Limits on dimensions ±0.010 unless otherwise specified.

FIG. 183.—AN315 aircraft plain nut.

this nut. The fiber nut cannot be used

1. When the temperature is in excess of 250°F.
2. When the bolt is subject to rotation.
3. When only one bolt is used in primary structure.

4. When oil or grease is present.
5. After it has been used several times.

When bolts are screwed into regular nuts, a certain amount of play exists between the threads and allows the nut to loosen under vibration. In the case of the fiber nut, a thread has not been cut in the fiber. Therefore, as the bolt cuts its own threads, the threads of the bolt are forced tight against the threads of the nut. This prevents the nut from loosening under vibration (see Fig. 184).

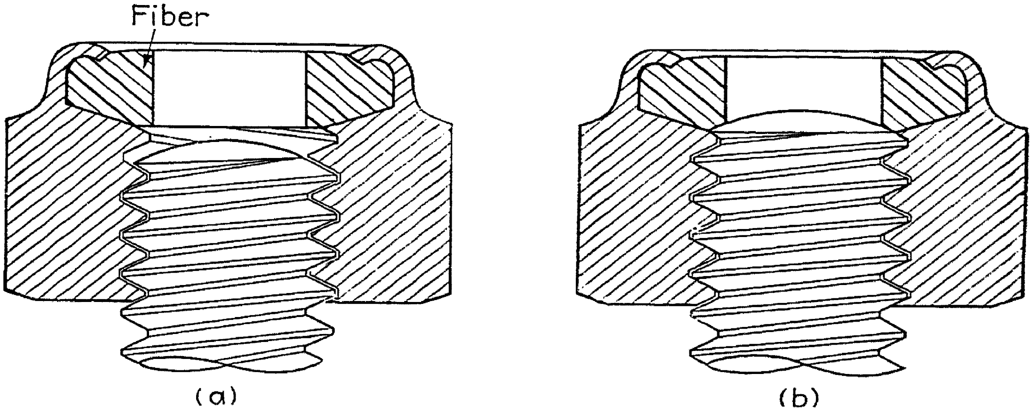


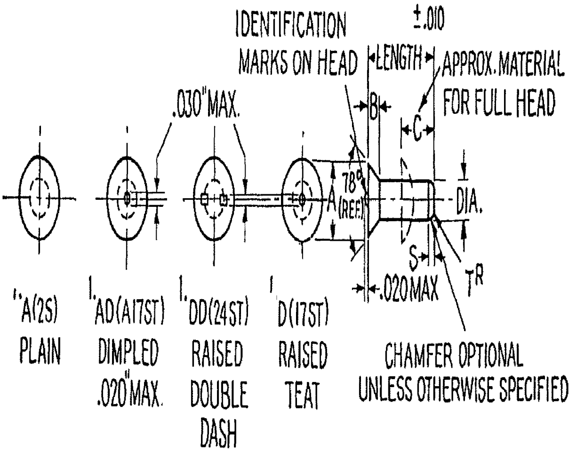
Fig. 184.—Fiber stop nut.

Rivets.—Aluminum rivets dominate the aircraft field. Their physical properties are described in the section on Metals. The AN Specifications for the most common are given in Figs. 185 and 186.

Screws.—Three general types of screw are used in aircraft construction, *viz.*, machine, metal, and wood. Machine screws are the most popular. They are used in any conceivable place where the extra strength of an aircraft bolt is not required. Metal screws are used to install items where it is impossible to place a nut. Woodscrews are used to attach parts to wood floors, etc. They cannot be used in primary structure to carry loads. Figure 18 shows various types of these screws.

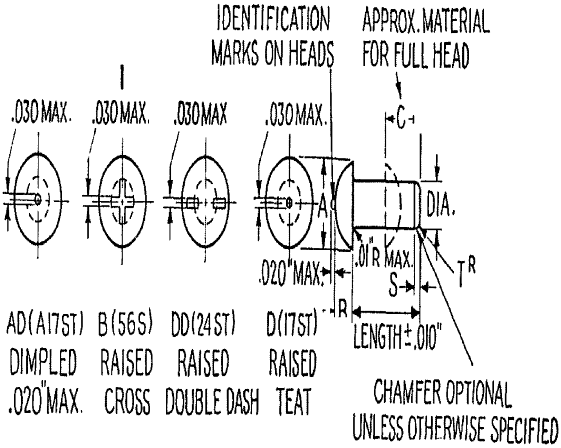
Metals

Before discussing metals it is necessary to define certain terms used to describe their properties.



AN425, Dimensions

Diameter	$0.062 \begin{smallmatrix} +0.003 \\ -0.001 \end{smallmatrix}$	$0.094 \begin{smallmatrix} +0.003 \\ -0.001 \end{smallmatrix}$	$0.125 \begin{smallmatrix} +0.0035 \\ -0.001 \end{smallmatrix}$	$0.156 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$	$0.187 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$	$0.250 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$	$0.312 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$	$0.375 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$
A	0.112 ± 0.006 (1)	0.170 ± 0.008 (1)	0.225 ± 0.011 (1)	0.282 ± 0.014	0.339 ± 0.017	0.452 ± 0.023	0.565 ± 0.028	0.675 ± 0.029
B	0.031 ± 0.005	0.047 ± 0.005	0.062 ± 0.005	0.078 ± 0.005	0.094 ± 0.005	0.125 ± 0.005	0.156 ± 0.008	0.187 ± 0.009
C	$\frac{3}{32}$	$\frac{9}{64}$	3/1[illegible]	$\frac{15}{64}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{5}{16}$
S	0.016	0.023	0.031	0.039	0.047	0.062	0.078	0.094
T^r	0.019	0.029	0.039	0.049	0.059	0.076	0.098	0.117



AN430, Dimensions

Diameter	$0.062 \begin{smallmatrix}+0.003\\-0.001\end{smallmatrix}$	$0.094 \begin{smallmatrix}+0.003\\-0.001\end{smallmatrix}$	$0.125 \begin{smallmatrix}+0.0035\\-0.001\end{smallmatrix}$	$0.156 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.187 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.250 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.312 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.375 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$
A	0.125 ± 0.006	0.187 ± 0.009	0.250 ± 0.012	0.312 ± 0.016	0.375 ± 0.019	0.500 ± 0.025	0.625 ± 0.031	0.750 ± 0.037
B	0.047 ± 0.005	0.070 ± 0.005	0.094 ± 0.005	0.117 ± 0.005	0.141 ± 0.007	0.188 ± 0.009	0.234 ± 0.012	0.281 ± 0.014
S	0.016	0.023	0.031	0.039	0.047	0.062	0.078	0.094
T^r	0.019	0.029	0.039	0.049	0.059	0.078	0.098	0.117
C	$\frac{3}{32}$	$\frac{9}{64}$	$\frac{3}{16}$	$\frac{15}{64}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{9}{16}$

AN425 and AN430, Lengths and Dash Numbers

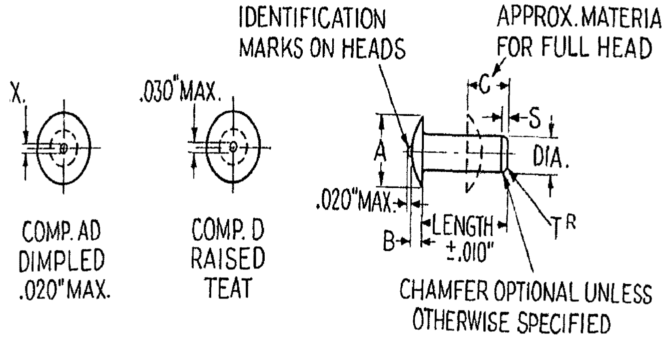
Diameter	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
$\frac{1}{16}$	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-12	2-14	2-16	2-18	2-20								
$\frac{3}{32}$		3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-12	3-14	3-16	3-18	3-20	3-22							
$\frac{1}{8}$		4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-12	4-14	4-16	4-18	4-20	4-22	4-24						
$\frac{5}{32}$			5-4	5-5	5-6	5-7	5-8	5-9	5-10	5-12	5-14	5-16	5-18	5-20	5-22	5-24	5-28					
$\frac{3}{16}$			6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-12	6-14	6-16	6-18	6-20	6-22	6-24	6-28	6-32	6-40	6-48		
$\frac{1}{4}$					8-6	8-7	8-8	8-9	8-10	8-12	8-14	8-16	8-18	8-20	8-22	8-24	8-28	8-32	8-40	8-48	8-56	
$\frac{5}{16}$							10-8	10-9	10-10	10-12	10-14	10-16	10-18	10-20	10-22	10-24	10-28	10-32	10-40	10-48	10-56	10-64
$\frac{3}{8}$									12-10	12-12	12-14	12-16	12-18	12-20	12-22	12-24	12-28	12-32	12-40	12-48	12-56	12-64

NOTE: AN425 is obtainable only in sizes inclosed with heavy lines. Size dash no. 2-2 is obtainable in AN425 only.

AN430-A2-12 = rivet, 2S Aluminum—not applicable for new design.
AN430-AD2-12 = rivet, A17ST Aluminum alloy, $\frac{2}{32}$ diameter, $\frac{12}{16}$ length.
AN430-B2-12 = rivet, 56S Aluminum alloy, $\frac{2}{32}$ diameter, $\frac{12}{16}$ length.
AN430-DD2-12 = rivet, 24ST Aluminum alloy, $\frac{2}{32}$ diameter, $\frac{12}{16}$ length.
AN430-D2-12 = rivet, 17ST Aluminum alloy, $\frac{2}{32}$ diameter, $\frac{12}{16}$ length.

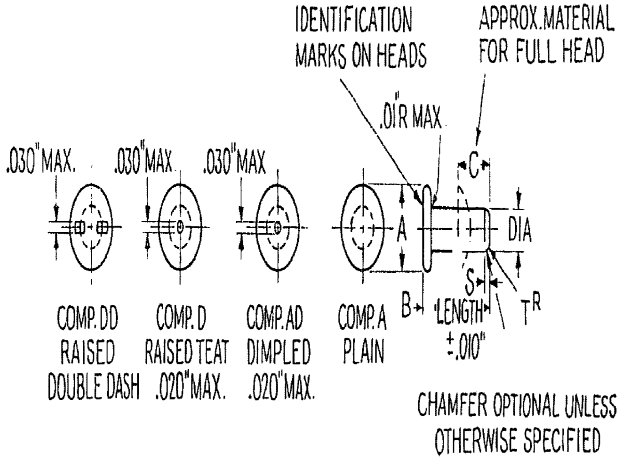
Dimensions in inches. Tolerances: Decimals ±0.010, unless otherwise specified.

FIG. 185.—AN425 countersunk and AN430 roundheaded aluminum rivets.



AN456, Dimensions

Diameter	$0.094 \begin{smallmatrix}+0.003\\-0.001\end{smallmatrix}$	$0.125 \begin{smallmatrix}+0.0035\\-0.001\end{smallmatrix}$	$0.156 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.187 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.250 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.312 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$	$0.375 \begin{smallmatrix}+0.004\\-0.001\end{smallmatrix}$
A	0.156 ± 0.010	0.235 ± 0.010	0.312 ± 0.010	0.390 ± 0.010	0.468 ± 0.010	0.625 ± 0.012	0.781 ± 0.015
B	0.031 ± 0.005	0.047 ± 0.005	0.063 ± 0.005	0.078 ± 0.005	0.094 ± 0.005	0.125 ± 0.005	0.156 ± 0.005
C	$\frac{9}{64}$	$\frac{3}{16}$	$\frac{15}{64}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{9}{16}$
S	0.023	0.031	0.039	0.047	0.062	0.078	0.094
T^r	0.029	0.039	0.049	0.059	0.078	0.098	0.117



AN442, Dimensions

Diameter	$0.062 {+0.003 \atop -0.001}$	$0.094 {+0.003 \atop -0.001}$	$0.125 {+0.0035 \atop -0.001}$	$0.156 {+0.004 \atop -0.001}$	$0.187 {+0.004 \atop -0.001}$	$0.250 {+0.004 \atop -0.001}$	$0.312 {+0.004 \atop -0.001}$	$0.375 {+0.004 \atop -0.001}$
A	0.125 ± 0.006	0.187 ± 0.009	0.250 ± 0.012	0.312 ± 0.016	0.375 ± 0.019	0.500 ± 0.025	0.625 ± 0.031	0.750 ± 0.037
B	0.025 ± 0.005	0.038 ± 0.005	0.050 ± 0.005	0.062 ± 0.005	0.075 ± 0.005	0.100 ± 0.005	0.125 ± 0.005	0.150 ± 0.007
C	$\frac{3}{32}$	$\frac{9}{64}$	$\frac{3}{16}$		$\frac{9}{32}$		$\frac{15}{32}$	$\frac{9}{16}$
S	0.016	0.023	0.031	0.039	0.047	0.062	0.078	0.094
T^r	0.019	0.029	0.039	0.049	0.059	0.078	0.098	0.117

Lengths and Dash Numbers

Diameter	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
$\frac{3}{32}$	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-12	3-14	3-16	3-18	3-20	3-22							
$\frac{1}{8}$	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-12	4-14	4-16	4-18	4-20	4-22	4-24						
$\frac{5}{32}$		5-4	5-5	5-6	5-7	5-8	5-9	5-10	5-12	5-14	5-16	5-18	5-20	5-22	5-24	5-28					
$\frac{3}{16}$		6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-12	6-14	6-16	6-18	6-20	6-22	6-24	6-28	6-32	6-40	6-48		
$\frac{1}{4}$				8-6	8-7	8-8	8-9	8-10	8-12	8-14	8-16	8-18	8-20	8-22	8-24	8-28	8-32	8-40	8-48	8-56	
$\frac{5}{16}$						10-8	10-9	10-10	10-12	10-14	10-16	10-18	10-20	10-22	10-24	10-28	10-32	10-40	10-48	10-56	10-64
$\frac{3}{8}$								12-10	12-12	12-14	12-16	12-18	12-20	12-22	12-24	12-28	12-32	12-40	12-48	12-56	12-64

Example of part No.:

AN456AD2-12 = rivet, aluminum-alloy compound AD(A17ST) – $\frac{2}{32}$ diameter times $\frac{12}{16}$ length.
AN456D2-12 = rivet, aluminum-alloy compound D(17ST) – $\frac{2}{32}$ diameter times $\frac{12}{16}$ length.

Dimensions are in inches. Tolerances: decimals ±0.010, angles ±$\frac{1}{2}$°, unless otherwise specified.

FIG. 186.—AN442 flatheaded and AN456 brazierheaded aluminum rivets.

Hardness: The ability of a substance to resist permanent deformation. The most common method for measuring hardness is the *Brinell hardness test*, and the results are given in the form of *Brinell's hardness numbers*. In this test a spherical ball is pressed into the surface of the material to be tested. The hardness is expressed by the ratio of the load to surface area of the indentation.

Brittleness: The tendency to fracture without change in shape. Brittleness and hardness are very closely associated, and hard materials are more brittle than soft materials.

Malleability: The property of a metal that allows it to be bent or permanently distorted without rupture. This property is present in soft metals, as lead and gold.

Ductility: The property of a metal that will allow it to be drawn out in tension without rupture. This property is essential in the manufacture of wire and tubing by drawing.

Elasticity: The ability of a substance to return to its original shape after the load that distorted it from its original shape has been removed.

Density: The weight of a unit volume of a material as compared with the weight of the same unit volume of water.

Resilience: The property possessed by a spring that allows it to push back after it has been compressed by an external force.

Stress and Strain: An external load applied to any object tends to stretch, compress, or shear that object. The tendency to change the shape of the object is called *strain*, and internal forces within the object resisting the strain are called *stresses*. The three forms of stress are *tension*, *compression*, and *shear;* these are expressed in terms of force per unit area as pounds per square inch. For a more detailed discussion of these two subjects, see Chap. II.

Elastic Deformation: When loads are applied to a body, the form of the body changes. If when these loads are removed the body will return to its original form, the change in form of the body above is called *elastic deformation.*

Permanent Deformation: When the loads of elastic deformation are increased to such an extent that the body fails to regain its original form upon removal of the loads, the deformation is called *permanent deformation* or *permanent set.*

Elastic Limit: The elastic limit is the greatest load per square inch of original cross-sectional area that a material can withstand without a permanent deformation.

Yield Point: The point at which there occurs a marked increase in permanent deformation without an increase in load. This is expressed in pounds per square inch of original cross-sectional area.

Ultimate Strength: The highest load required to break an object, divided by the original cross-sectional area. For more information on this subject, see Chap. II.

Steel.—Carbon and other elements are combined with iron in varying percentages to give a wide range of steels of various

physical properties. In order to obtain the high-grade metals required by aircraft an exact control of all the alloying elements must be exerted. The amount and manner in which these elements are added greatly affect the ultimate properties of the steel.

The most important of these alloys and their effects on the properties of steel will be discussed below.

Carbon is the most important element present in steel. The classification of iron and steel is generally dependent upon the percentage of carbon present. Plain carbon steel also contains small amounts of silicon, manganese, sulphur, and phosphorus. The last two elements are harmful impurities, to be kept as low as possible. The ultimate strength, the hardness, and the heat-treating range increase with the increase of carbon present. Thus, the ductility, malleability, toughness, impact resistance, and weldability of steel decrease with this increase of carbon. In general, low carbon steels are used for fittings, welded parts, etc., where ductility is necessary. High carbon steels are used for springs, where hardness is required. Medium carbon steels are used for forged fittings, landing-gear parts, etc., where toughness and ductility are both required.

Manganese is the second most important alloy in steel. It eliminates harmful ferrous oxides and sulphur and improves forging qualities by reducing the brittleness of the steel.

Silicon in small quantities is used to improve the ductility of metal and to produce a sound product.

Sulphur in excess of 0.06 per cent gives a brittle metal called *hot short,* because the steel breaks up under hot rolling.

Phosphorus in excess of 0.05 per cent causes *cold shortness,* because of brittleness when the steel is cold.

The metals most commonly used to alloy steel are nickel, chromium, molybdenum, vanadium and tungsten. Small quantities of titanium and columbium are also used in the manufacture of "stainless steels."

Nickel, a white corrosion-resistant metal, combines readily with steel to give increased strength, yield point, and hardness without a reduction in ductility. It also improves the corrosion resistance of steel, being a principal ingredient to "stainless steel."

The gray hard metal, *chromium,* is used to increase impact hardness, strength, corrosion resistance, and wear resistance. It also improves heat-treating properties.

Small amounts of *molybdenum* have the same effect as large amounts of other elements. It produces a fine-grain metal of excellent welding and heat-treating properties. It also produces a tough but ductile metal, used extensively in the manufacture of tubular structure, as landing-gear parts, fuselages, and motor

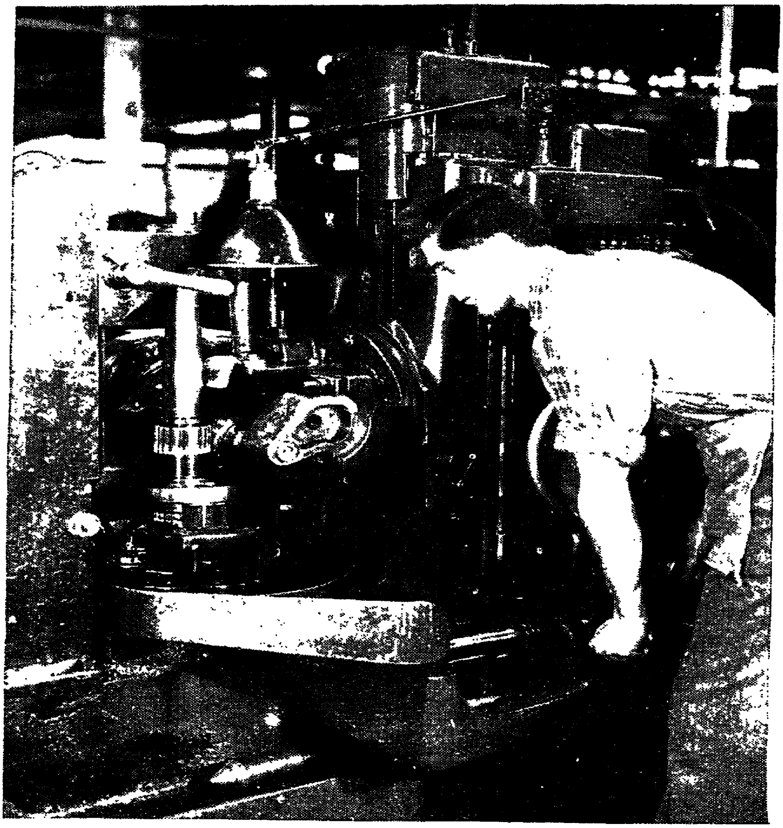


FIG. 187.—Cutting the splines for a reduction driving gear on a Wright 14-cylinder-engine crankshaft.

mounts. This alloy steel can be readily heat treated, forged, and machined.

In order better to classify the above steels and their alloys, the S.A.E. has set up a numerical index system. Instead of writing out all the properties of the metal on the blueprint, the designer need give only the S.A.E. number. The first digit indicates the type to which the steel belongs; thus, 1 indicates carbon steel; 2 indicates nickel steel; 3 indicates nickel-chromium steel; 4 indi-

cates molybdenum steel; 5 indicates chromium steel; 6 indicates chromium-vanadium steel; 7 indicates tungsten steel; and 9 indicates silicon-manganese steel. In the case of the simple alloy steel the second digit generally indicates the approximate percentage of the predominating alloy element. Usually the last two or three digits indicate the average carbon content in hundredths of 1 per cent. Thus, 2340 indicates a nickel steel of

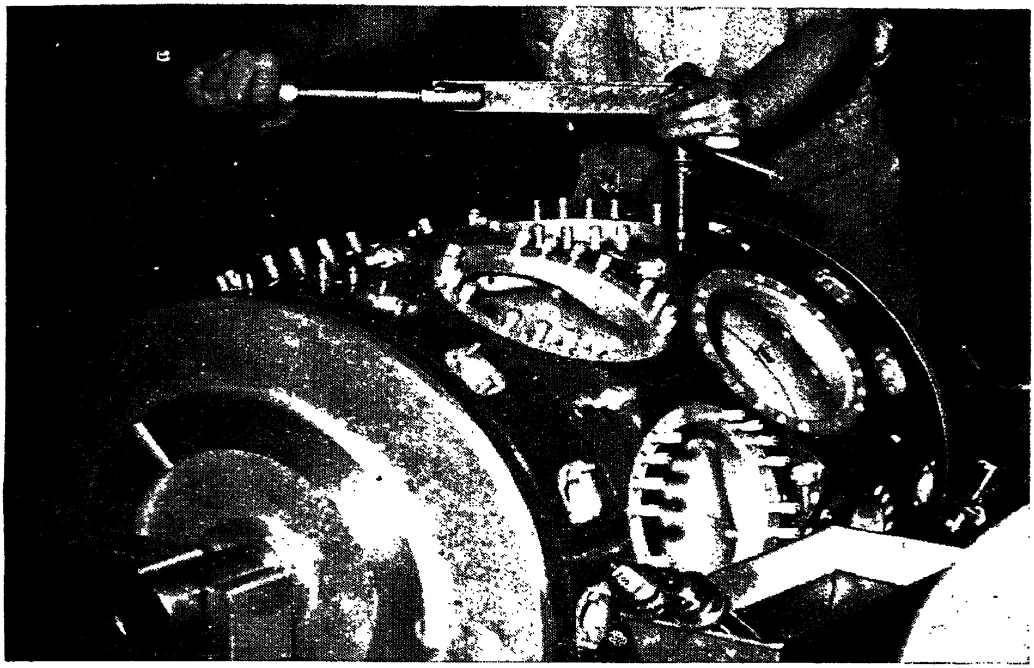


FIG. 188.—Installing cylinder-hold-down studs on a Wright double-row engine. These are S.A.E. 2330 steel.

approximately 3 per cent nickel and 0.40 per cent carbon. The prefix X is used to denote variations in range of manganese, sulphur, or chromium.

Since it is impossible to give all S.A.E. steels here, only those most commonly used in aircraft will be discussed.

S.A.E. 1020.—This steel is used for casehardened parts such as bushings, stampings, etc. When casehardened, this steel has a core strength of 60,000 p.s.i., with good ductility. In the normal state it has an ultimate tensile strength (U.T.S.) of 55,000 p.s.i. and a yield strength of 36,000 p.s.i. This steel can be machined well and can be brazed or welded very easily.

S.A.E. 1025.—This steel is better known as mild carbon steel or cold-rolled stock. It is used where bending is required and has a U.T.S. of 55,000 p.s.i. and a yield strength of 36,000 p.s.i. When used for aircraft parts, 1025 can be heat treated to develop a minimum strength of 70,000 p.s.i. This material machines well and can readily be brazed or welded.

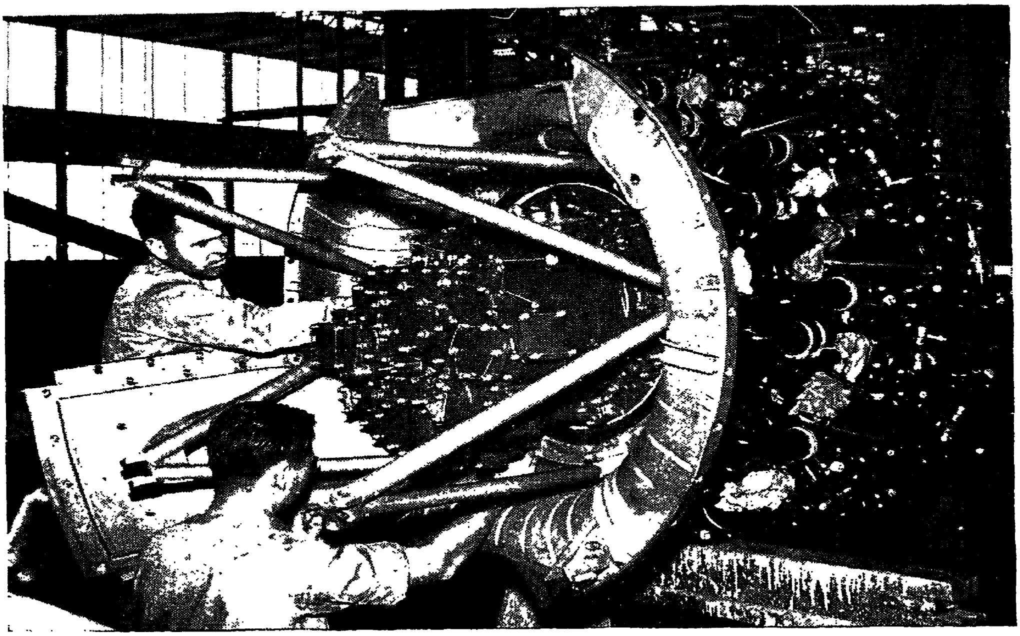


FIG. 189.—Attaching a chrome-moly welded-steel-tube motor mount to a twin-row radial engine before installation in a Lockheed Ventura.

S.A.E. 1095.—This steel is a high carbon steel used for springs, hinge pins, etc. It is sometimes referred to as *piano wire* or *music wire.* When obtained in bar-stock form, it is also referred to as *drill rod.* This steel has a U.T.S. of 350,000 to 225,000 p.s.i. It cannot be readily machined or drilled in the heat-treated condition, but it should be worked in the annealed condition and heat treated after working.

S.A.E. 2330.—This is known as nickel steel and possesses good strength and great toughness. It can be obtained in almost all conditions, as sheet, rod, forging, heat treated, or annealed. When heat treated this steel develops a U.T.S. of 125,000 to 150,000 p.s.i. and a yield strength of 100,000 to 120,000 p.s.i.

When used for aircraft bolts, tie rods, etc., it is heat treated to 125,000 p.s.i. It can be bent over a diameter equal to its thickness, machines well, but should not be brazed or welded, as welding reduces its U.T.S. to 60,000 p.s.i.

S.A.E. X4130.—This is chrome-molybdenum steel, better known as *chrome-moly.* It is used extensively in aircraft construction where tube and sheet parts are needed. This metal can also be used for small forging. Its wide use is due to its excellent welding characteristics, its ease of forming, and its response to heat treatment. For this reason, it can be obtained in almost all sizes, sheets, and tubes.

Sheets and tubing are usually purchased in the normalized state and have a U.T.S. of 90,000 p.s.i. and a yield strength of 70,000 p.s.i.

When it is heat treated, the physical properties may be as follows:

	U.T.S., p.s.i.	Yield strength, p.s.i.	Shear	Bearing
From	125,000	100,000	80,000	175,000
To	200,000	150,000	125,000	210,000

After the heat-treated metal has been welded, only 80 per cent of these figures should be used.

Control-system parts are heat treated to. 125,000 p.s.i., U.T.S.
Wing-hinge fittings are heat treated to. 150,000 p.s.i., U.T.S.
Landing-gear parts are heat treated to. . 175,000 to 200,000 p.s.i., U.T.S.

Chrome-moly can be welded with either oxy-acetylene or an arc welder. Welding, however, reduces the properties of the heat-treated parts because it has a normalizing effect on the metal near the weld. Welding due to shrinking sets up internal stresses in the tubing. This must be removed after welding by normalizing. Also, rigid jigs should be used to keep this shrinkage under control. This material has very wide use in the construction of welded-tube fuselages, wing trusses, and landing-gear parts.

Heat Treatment of Steel.—Since weight is an important factor in the performance of aircraft, the manufacturer must get the

ultimate strength-weight ratio possible from aircraft metals. He also must obtain a uniform product; *i.e.*, the strength at the edge of a sheet must be the same as the strength in the center, and the strength of two sheets must be the same, within small percentages.

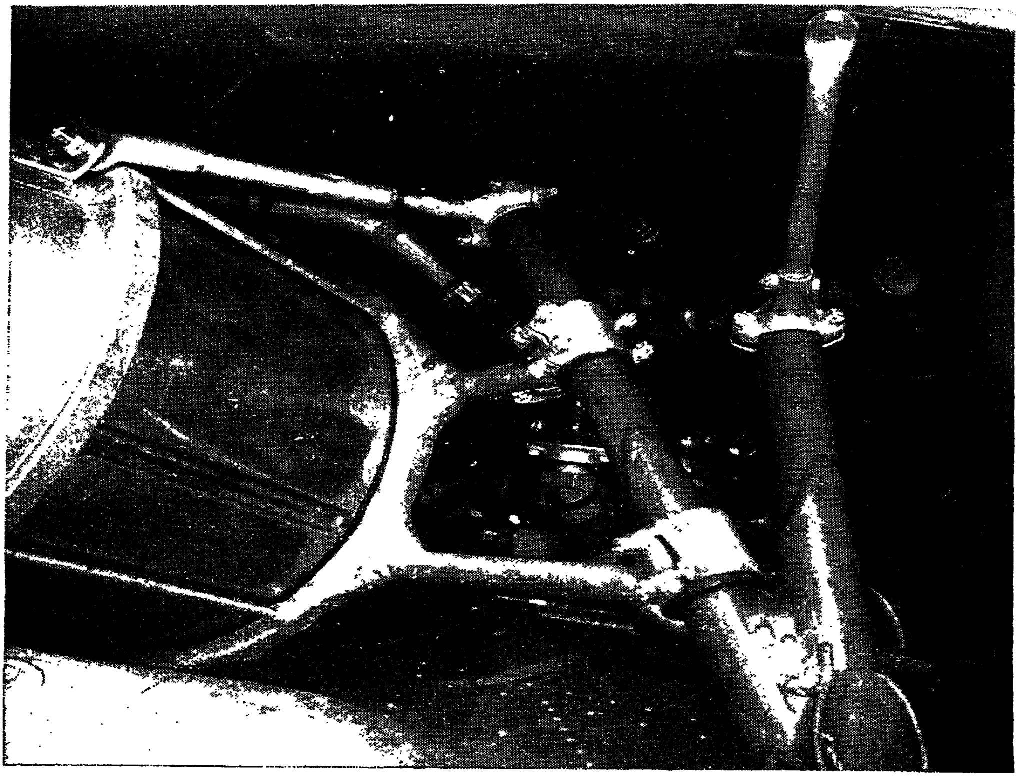


FIG. 190.—Oil-radiator installation on a Douglas DC-3 showing different welds.

Since the heat treating of steel greatly affects its ultimate properties, it is important that such properties be controlled accurately. This branch of steel manufacture in recent years has become one of the most important parts of the field. Heat treatment of any metal is the heating and cooling of that metal in the solid state to obtain special desired properties.

When steel is heated to 1300 to 1600°F., its internal structure is altered, giving a fine-grain homogeneous metal. This temperature range is called the *critical range*.

Heating steel above the critical range, keeping it at that temperature until uniformly heated, and then allowing the steel to cool slowly is called *annealing*. Cooling is obtained by shutting off the furnace and allowing the steel to cool with the furnace. This produces a soft ductile metal of the lowest strength value possible. This process is used to relieve all internal strains induced in the metal.

Normalizing is a process, similar to the process of annealing, by which the steel is heated to a temperature above the critical range and allowed to remain until uniformly heated, after which there follows cooling in still air at ordinary temperatures. Normalizing is not so effective as annealing; however, it is much quicker and is more extensively used. It relieves internal strain and softens the metal somewhat. Normalized metal is approximately 20 per cent stronger than fully annealed metal.

Heating the metal above the critical range, soaking at that temperature until the mass is uniformly heated, and then immersing it quickly in brine, water, or oil is called *quenching*. Quenching produces a metal of fine grain and maximum hardness and tensile strength with minimum ductility and internal strain. In the hardened form metal does not lend itself well to working and should be worked before hardening. In some instances the metal can be hardened to such an extent that a severe blow with a hammer will shatter it.

The second process in the heat treating of metal is called *drawing*, sometimes called *tempering*. This consists in heating the metal in the hardened state to a temperature just below the critical range, soaking it at that temperature until uniformly heated, and quenching in brine, water, or oil. This treatment relieves internal strain and hardness caused by the hardening process. It restores the ductility with only a slight reduction in strength.

Sometimes it is desirable to obtain both a hard wearing surface, as on the faces of gears or axles, and also a tough ductile core to resist shock and stresses. The method or process employed to obtain the hardened surface is called *casehardening*. It is accomplished by heating the metal in contact with wood, charcoal, bone, or coke. That is, the metal, surrounded by the charcoal, is placed in a box, sealed airtight, and put in an oven. This is heated to a temperature of around 1700°F., which allows the

carbon to penetrate the outer surfaces of the metal. This produces a very thin layer of high carbon steel. This outer layer has excellent wear qualities.

Stainless Steel.—One of the newest metals in the industry is corrosion-resistant steel, better known as *stainless steel.* Its use

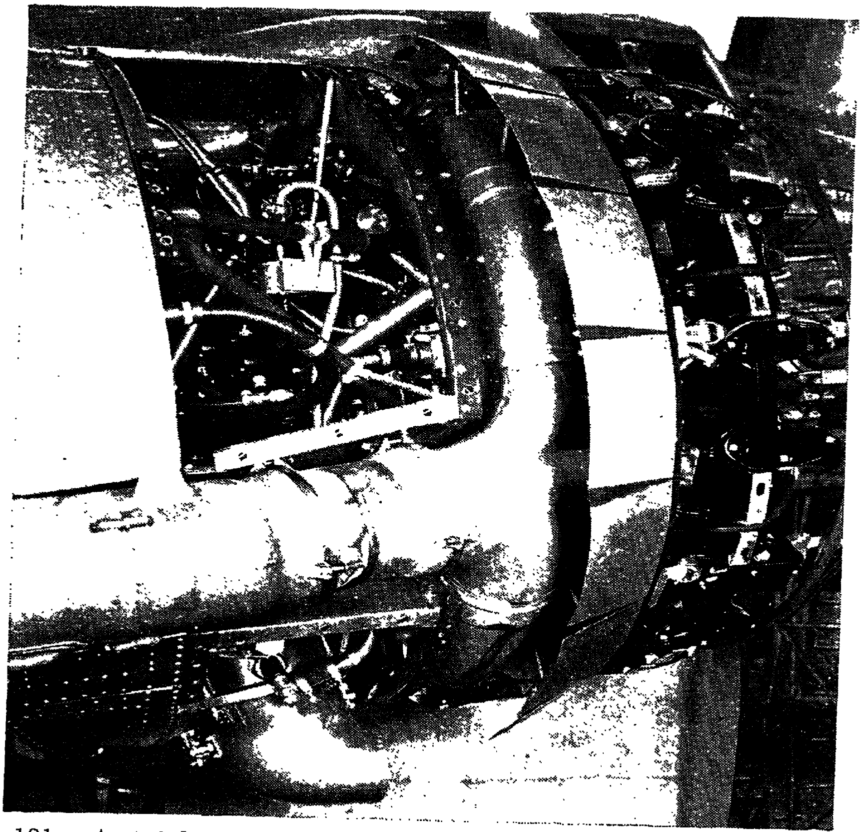


FIG. 191.—A stainless-steel exhaust collector ring on a Wright-engine installation of a Douglas DC-3. This also shows the accessory section of the engine-mount assembly.

is growing rapidly, which makes it obtainable in a wide variety of forms. The most common steel of this group used in the aircraft industry is 18-8. This includes steels containing 17 to 25 per cent chromium, 7 to 13 per cent nickel, and approximately 0.20 per cent carbon. In the fully annealed condition it is nonmagnetic but may become magnetic if severely work hardened. This steel may be furnished in sheets with the following

finishes: No. 1—hot rolled, annealed, and pickled; No. 2B—full finish (bright cold rolled); No. 2D—full finished (dull cold rolled); No. 4—standard polish; No. 6—standard polish, Tampico brushed; No. 7—high-luster finish; No. 8—mirror finish.

The chemical properties of corrosion-resisting steel aid its corrosion resistance only to a slight degree. The majority of its corrosion-resistant properties are obtained from a tough invisible oxide film present on the surface of the metal. To obtain this film, the surface must be free of all impurities. This surface condition may be accomplished by polishing or pickling. Polishing is so expensive that pickling is ordinarily used. In the event that stainless steel is to be polished, it should first be lightly sandblasted to remove all scale and then polished with a cotton buffing wheel and fine buffing compounds. Wire brushes should never be used. After welding the scale must be removed in the same manner.

To prevent discoloration of corrosion-resisting steel after working, by restoring the protective oxide film, all foreign particles embedded in the material during this operation should be removed by washing the steel well or immersing it in a hot solution (approximately 125 to 150°F.) of 15 to 20 per cent nitric acid. The metal should then be thoroughly washed in hot water.

The strength and hardness of 18-8 steel can be increased only by cold working. The strains set up by this cold working, if desired, can be removed by annealing.

Hardenable chromium steel, which varies slightly from the 18-8 chromium-nickel steel, can be hardened by heat treatment. It contains 12 to 18 per cent of chromium and about 1 per cent carbon. This type is used mainly for cutlery, etc.

There is still another type of stainless steel, but it is not used in the manufacture of aircraft; therefore, it will not be discussed here.

When 18-8 steel is heated to temperatures in the range of 1000 to 1600°F., as would be the case in welding, intergranular corrosion takes place, caused by the precipitating out of unstable carbides along the grain boundaries. Since precipitation does not take place immediately but requires a certain interval of time, spot welding is far more satisfactory than arc welding. The carbides lower the corrosion resistance of the metal and

increase the brittleness of the metal. This occurs in the metal just adjacent to an oxy-acetylene weld and would cause the metal to crack or give way at this point. To overcome this condition a "stabilized" metal has been produced. It contains additions of titanium or columbium, which form stable carbides that do not precipitate out. The stabilized metal is used in almost all cases in the manufacture of aircraft.

After arc welding or gas welding, 18-8 steel should be annealed to remove internal stresses. This will eliminate the possibility

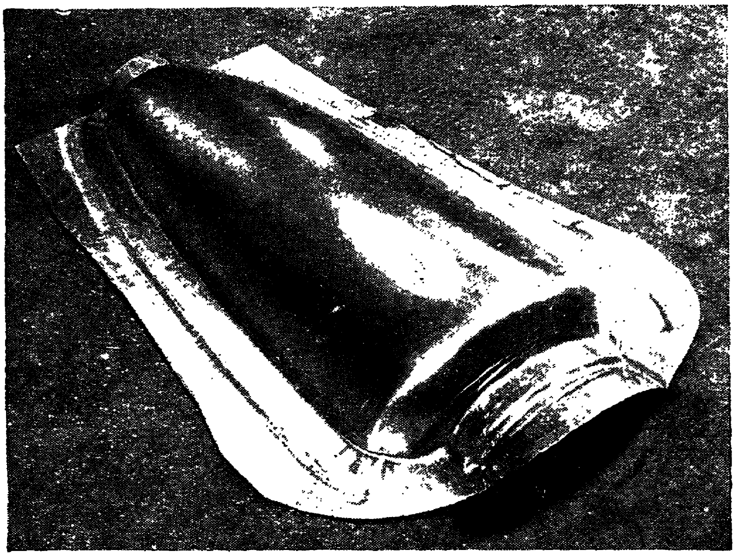


FIG. 192.—A stamped stainless-steel part. (*Courtesy of Curtiss-Wright Corp.*)

of cracks along the layers adjacent to the weld. This practice should be adhered to particularly in the case of welded exhaust stacks. To anneal this metal, heat it to at least 1850°F. or better to 2050°F. and cool rapidly. Never allow the metal to cool slowly, or the undesirable carbides will precipitate.

Corrosion-resisting 18-8 may be joined by spot or seam welding and lead solder without forming the undesirable precipitate. For this reason spot and seam welding are the most widely used.

The U.T.S. for the annealed 18-8 is 80,000 p.s.i.; yield strength is 35,000 p.s.i. In the full hard, the U.T.S. is 185,000 p.s.i., and the yield strength is 140,000 p.s.i. The radius of bend varies from one thickness on the annealed to six times the thick-

ness on the full hard. In the annealed form an 18-8 can be worked to almost any shape.

In cutting 18-8 corrosion-resistant steel, a high-speed, heavily weighted saw should be used, so that the first stroke cuts the metal. If the saw passes over the metal without cutting, the

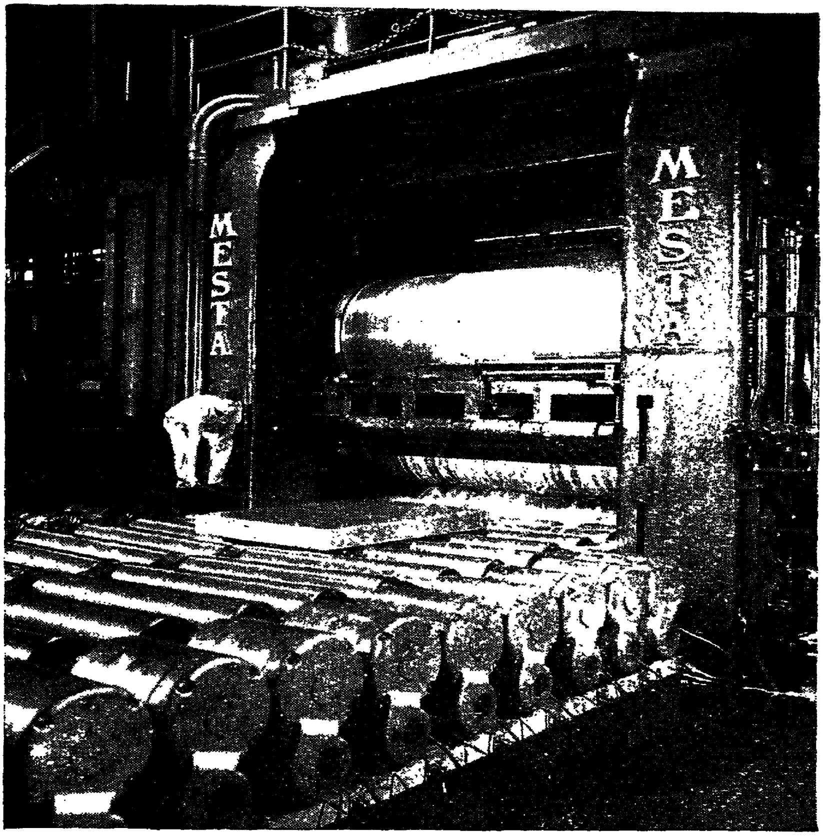


FIG. 193.—Breakdown mill which starts the process by which aluminum ingots are rolled into aluminum sheets for aircraft. (*Courtesy of Aluminum Co. of America.*)

metal quickly work hardens, making cutting difficult if not impossible. In drilling, a high-speed, sharp drill should be used, and care should be taken that it cuts at all times. It should be well lubricated with an oil-sulphur lubricant and removed frequently to cool.

Its exceptional corrosion-resistant qualities have permitted 18-8 corrosion-resistant steel to be used in the fabrication of

internal structure, as tail assemblies on seaplanes and exhaust collector rings. Its toughness and wear qualities have made possible its use in places where exceptional wear qualities are desirable. However, at the present date only one aircraft has been manufactured wholly of this material.

Aluminum.—Because of light weight and great strength, aluminum and aluminum alloys are extensively used in the construction of present-day aircraft. Aluminum also has relatively high corrosion-resistant qualities. Moreover, certain forms can be welded easily. Its ductility and great strength permit ease of fabrication, and it lends itself well to rolling, stamping, riveting, etc.

Aluminum is present in most clay soils and rock, but in insufficient quantities to render its extraction practical. Its principal source is the ore bauxite, which is composed largely of aluminum oxide mixed with impurities. After the removal of these impurities by chemical processes, pure aluminum oxide, called *alumina*, is obtained. This alumina, or aluminum oxide, is reduced to aluminum by an electrolytic process.

The metallic aluminum is then cast into pig form. During the casting of the pigs, alloys are added. From these many of the structural shapes are wrought by rolling, drawing, extruding, or forging. The most common forms used in aircraft construction are sheet tubing, wire, bar, angle channel, V section, and U section, but almost any desired shape can be obtained upon request. Some aluminum alloys lend themselves well to castings made in sand molds, permanent molds, or die casting. Cast material, however, does not possess the strength of the wrought metal.

The various aluminum alloys are identified by number. To indicate wrought alloys the letter S is added; to indicate casting, no letter or the letter T is added. Thus 3S, 4S, 14S, 17S, 24S, and 25S are all wrought alloys having different chemical compositions and physical properties. 43, 142, and 195T are different casting alloys. In some cases the alloy number is preceded by a letter, as A17S. This letter indicates an alloy of slightly different chemical composition from the normal alloy, 17S.

Wrought alloy can be manufactured in many different tempers, varying from the full-annealed to the full-hard state. When the alloy is in the soft, or annealed, state, the letter O is placed

after the letter S, at 3SO. When the alloy has been strain hardened or cold worked, the letter H is added to the letter S, H meaning hard. Fractional intermediate hardnesses are noted by $\frac{1}{4}$H, $\frac{1}{2}$H, and $\frac{3}{4}$H, as 3SO, 35-$\frac{1}{4}$H, 3S-$\frac{1}{2}$H, and 3S-$\frac{3}{4}$H.

When the wrought alloys are hardened by heat treatment, the letter T follows the letter S, indicating heat treatment, as 17ST, 24ST, 25ST, and 53ST.

FIG. 194.—Cleaning an aluminum cylinder head after it comes out of the mold. (*Courtesy of Wright Aeronautical Corp.*)

If the heat-treatable alloys are in the full-annealed state, they are designated as above, as 17SO, 24SO, 25SO, and 53SO.

When the heat-treated alloys are strain hardened to improve their physical properties, the letter R is inserted between the letters S and T, as 17SRT.

Some alloys require a second heat treatment to develop their full strength. After the second treatment the letter T is placed after the letter S. When these alloys receive only the first

treatment, they are identified by writing W after the letter S, as 25SW. This alloy, however, is very seldom found in the manufacture of aircraft.

Wrought aluminum alloys may be broadly classified in one of the two following groups: strain-hardened or heat-treatable alloys. The physical properties of strain-hardened alloys may be improved only by cold working. The physical properties of heat-treatable alloys are improved mainly by heat treatment.

The strain-hardened alloys can be obtained in any of the following tempers: 0, $\frac{1}{4}$H, $\frac{1}{2}$H, $\frac{3}{4}$H, and H. The most common alloys falling in this group are 2S, 3S, 4S, and 52S.

These alloys vary from 99 per cent pure aluminum to 96 per cent. Because others give greater strength, these alloys are never used for primary construction; however, since they can easily be bent, formed, and welded, they are used to make cowling, tanks, and fairings. 2S and 3S are widely used for drawing, spinning, and sanding; however, where greater strength is required, 4S and 52S are used. Tanks are manufactured from 2S and 3S, while 52S is used for large cowling.

Heat treatment of these alloys does not improve their properties. Greater strength may be obtained only by cold working. In the fabrication of these metals it may be desired to anneal them from time to time to keep them from becoming too hard. To accomplish this, 2S and 52S should be heated to a temperature of 650°F. and allowed to cool in the air. 3S and 4S should be heated to a temperature of 750°F. and allowed to cool in the air.

These metals are easily welded by electric arc or by oxy-acetylene or oxy-hydrogen flame. In the majority of cases, seams to be welded are not butted directly together, as for steels, but are flanged before butting, and the flanges melted down the desired amount. In the construction of tanks the flanges are long to allow for tank repair and rewelding. In the manufacture of flat surfaces where a smooth joint is desired, the flanges are short and are burned down to the level of the sheet. Welding rod of the same composition as the metal being welded furnishes a more satisfactory weld and whenever possible should be used.

Welding anneals the metal on both sides of the weld. The weld, however, is in a cast condition. If the weld is not ground down to give a smooth surface, it will develop greater strength

than the adjoining metal. Sometimes welded seams are hammered after welding to increase the strength somewhat.

The heat-treated alloys are stronger than the strain-hardened alloys and can be obtained in the soft-annealed condition, the heat-treated condition, or the heat-treated and cold-worked

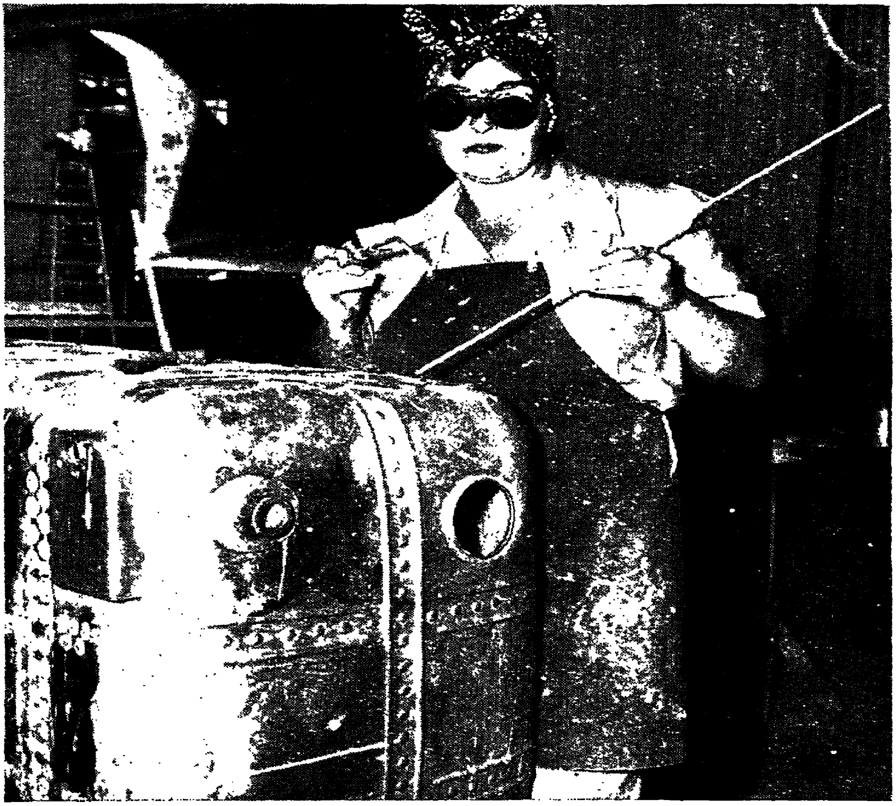


FIG. 195.—Welding an aluminum gas tank. (*Courtesy of Eastern Air Lines, Inc.*)

condition. Some of these alloys are heat treated to an intermediate condition.

Heat-treated aluminum alloys may require one or both methods of heat treatment, the *solution heat treatment* and the *precipitation heat treatment.* The 17S and 24S alloys require only the solution heat treatment; they will develop their full properties by "aging" in air at room temperature. This process requires four days for completion. Some alloys, as 25S and 53S, require both heat treatments to develop their full properties.

In the solution heat treatment the temperature of the metal is raised and maintained by placing the metal in a heated salt bath or in an electrical furnace. While the metal is at this high temperature, the alloying elements that give greater strength and hardness become more soluble in the solid aluminum. When the solution is complete, the metal is removed from the furnace and *quenched at once* in water.

Accurate temperature control is absolutely necessary during this heat treatment, or the material will not develop full properties. The limits for 17S range from 930 to 950°F. and for 24S from 910 to 930°F. If the temperature is too high, metal blisters develop; if the temperature is too low, complete solution does not take place

If more than a few seconds elapse between removal from the furnace and quenching, the corrosion resistance of the metal will be seriously affected. For this reason, when the metal is removed from the furnace a hood is placed over the work to prevent cooling en route to the quenching bath. Since it is necessary that the quenching bath temperature be less than 90°F. at the start of the quench and not more than 150°F. at the completion, it is a good idea to have water continually flowing in and out of the bath. This also helps prevent the salt from the metal remaining in the bath. After quenching the metal should be thoroughly rinsed to ensure that no salt has remained on the metal; otherwise, the corrosion-resistant properties of the metal will be greatly affected. Rinsing water temperature must be below 150°F.

In the case of some alloys, aging will not take place at room temperature and the alloy must be aged at a higher temperature. Such alloys, after quenching for the solution heat treatment, are raised to 300°F. and soaked at this temperature for 12 to 18 hr., a portion of the elements in solution being allowed to precipitate out. This form of heat treatment is the precipitation heat treatment mentioned above. When it takes place at ordinary room temperatures, as it does in 17S and 24S, it is called *natural aging*. Although this aging is 90 per cent complete after 24 hr., it requires 4 days for completion.

If it is necessary to form aluminum alloys, this must be performed within 1 hr. after solution heat treatment or the aging process will have progressed too far and the metal may crack.

If the metal is maintained at a temperature below 32°F., the aging of 17S and 18S may be retarded as much as 24 hr. This is usually accomplished by placing the metals in iceboxes containing dry ice.

Sometimes it becomes necessary to anneal heat-treated alloys that have become work hardened, in order to permit additional forming. It may also be necessary to anneal strain-hardened materials that have become hardened by working. This may be

FIG. 196.—Coiled aluminum-sheet strips about to be placed in annealing furnaces. The furnaces are in the upper left-hand corner. (*Courtesy of Aluminum Co. of America.*)

accomplished by heating the material to a temperature of 640 to 670°F. and allowing it to cool slowly in air, a method, however, that does not completely anneal the metal. Should it be necessary fully to soften heat-treated materials to remove all effects of previous heat treatment, the aluminum alloy must be heated to 750 to 800°F. and soaked at this temperature for at least 2 hr. As in the case of steel, it must be cooled at a very slow rate not to exceed 50°F. per hr. until it has reached 500°F. Beyond this point the metal may be cooled in air. In order to obtain this slow rate of cooling, it is customary to leave the metal in the furnace and allow it to cool with the furnace, after this has been

shut off. After the fully annealed metal has been worked, it will be necessary to heat treat it again to obtain its full properties.

Unlike strain-hardened metals, heat-treated metals should not be welded by gas flame, as gas welding destroys its properties. If it is desired to weld this metal, it should be done only by spot welding. Owing to its greater strength, the heat-treated material is used extensively in the manufacture of all structural parts in aircraft; the work-hardened metals are used only on non-structural members.

In comparison with other metals, aluminum may be considered a corrosion-resistant material. This property is reduced somewhat with the addition of alloy. Under any circumstance these metals should receive a protective coating if they are to be subjected to adverse conditions, as in the case of a seaplane.

One form of corrosion affecting aluminum alloys is the flaking away of the material on the outer surface, owing to electrolytical action taking place between it and impurities or other metals. Since aluminum falls below all metals used in aircraft, in the galvanic series (even its alloys), it will be attacked by all metals. This action is greatly accelerated by the presence of moisture and is prevalent in inaccessible places that may be poorly vented. It can be corrected by cleaning the metal well and painting with a very thin coat of zinc chromate primer, P27B, or reduced lionoil.

A second form of corrosion is called *intercrystalline corrosion* and is found only in the alloys that contain copper, as 17S and 24S. This form is due to improper heat treating or delayed quenching. It is far more dangerous than the first type, as it gives no outward indication of its presence. By spreading throughout the grain boundary, it reduces the ductility and strength of the metal.

In order to improve the corrosion-resistant properties of certain alloys and thus lengthen the useful life, these metals (17S and 24S) have been coated with thin layers of pure aluminum. So treated they are known as *Alclad*. Such coatings not only protect the alloy by electrolytical action but also protect it from small surface scratches. The electrolytical action protects the end of the sheet, where it is cut for fabrication. Although Alclad has far better corrosion-resistant properties than the alloy metals, it should be painted if subjected to severe corrosion conditions.

New Alclad has less strength than the standard alloy, but after years of service Alclad will still develop almost the same strength, whereas the standard alloy will lose a great deal of its strength. At present, owing to restrictions on its manufacture, Alclad can be obtained only in sheet and wire form.

Heat treating Alclad must be done with care and with a minimum time of soaking, in order to prevent the aluminum coating from merging with the alloy.

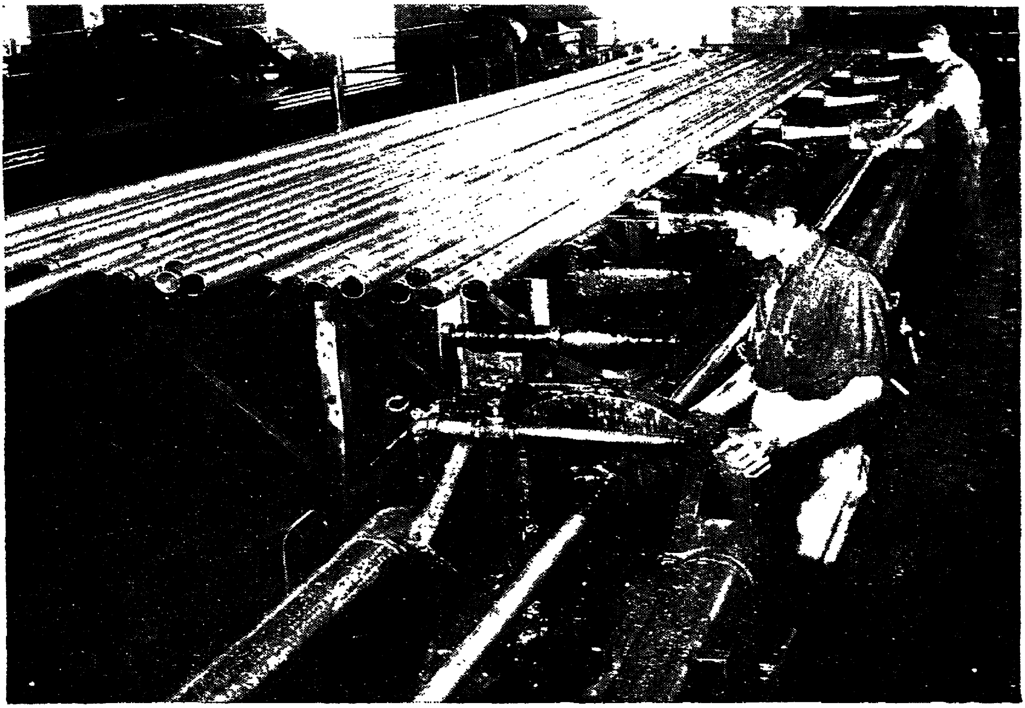


FIG. 197.—Forming aluminum tubing by means of extrusion on a drawbench. (*Courtesy of Aluminum Co. of America.*)

Aircraft construction requires many structural shapes, as channels, angles, T sections, and Z sections. These shapes are produced by forcing a cylinder of aluminum alloy heated to a temperature of 750 to 850°F. through a die having the aperture of the desired shape. This is done by means of a hydraulic ram. Since this metal has been forced through a die, the grain of the extrusion will not be so fine or so homogeneous as the rolled or forged material; however, extrusions have performed very well in service.

Aluminum alloys may be forged to close limits by hammer forging or drop forging. Such products are found to be very light but strong and of uniform structure free from blowholes. Only a few thousandths of an inch need be allowed for finished machining.

Until recently, enough information was not available to render spot welding very satisfactory; however, at present this process is growing in favor among the leading manufacturers. Alclad 17ST and 24ST are the most satisfactory materials for this process. Under any condition, however, the metal must be absolutely clean or fusion will not take place.

All leading aircraft manufactured today employ aluminum rivets. These may be classified into two groups, nonstructural and structural. Nonstructural rivets (2S and 3S) are used on welded tanks, etc. Structural rivets may be subdivided into two additional groups, those which must be heat treated before they can be driven and those which can be driven as received. It is possible to drive A17ST, 53S, and 53SW rivets as received, but it is necessary to heat treat 17S and 24S rivets before they can be driven. When it is necessary to obtain the greatest strength possible from a rivet, 17S and 24S rivets are used. Although the 24S rivet develops greater strength, it is more difficult to drive than the 17S and must be driven within 20 min. after heat treatment. Therefore, it is not widely used. The 17S rivet may be driven at any time within 1 hr. after heat treatment. Because of ease of handling and minimum equipment employed, the A17ST rivet is now being extensively used in the construction of aircraft. These rivets are also very satisfactory for repairing in the field, as no heat-treating furnace or equipment is necessary. The 24S rivets may be identified by two small dashes at the end of the diameter on the head, the 17S rivets by a small teat in the center of the head, the 3S and 2S rivets by a smooth head, and the A17ST rivets by a small dimple in the center of the head. 53S rivets are used where corrosion-protective properties are desirable, sometimes being used with Alclad (see Figs. 185 and 186).

In heat treating rivets, it is necessary either to heat treat small batches of rivets at frequent intervals to stay within the time limits or to keep the rivets in iceboxes to retard aging. As in the case of heat-treatable alloys, this practice will keep the rivets soft for approximately 24 hr. If the rivets have not been

used up within the time limit, they may be heat treated without any damage to the rivets.

Rivets may be heat treated either in an air furnace or in a salt bath. If the salt bath is used, some arrangement should be made to prevent the rivets from coming in contact with it. The temperature of the bath should vary from 930 to 950°F. The time required for soaking should vary from 5 to 30 min., depending upon the size of the rivets. When the rivets are removed from the oven, like heat-treatable alloys they must be quenched in water at once. Delayed quenching will cause the rivets to become brittle.

Copper and Copper Alloys.—1. *Copper* is used mainly for gas and oil lines and electrical wiring in aircraft construction.

Aircraft tubing is drawn seamless tubing in the full-annealed condition. Should it be work hardened by forming, it must be annealed before installation in the aircraft. Annealing is accomplished by heating in an air furnace to approximately 1100 to 1200°F. and quenching in water. This material must be 99.90 per cent copper with the following properties:

S.A.E. 75

U.T.S	32,000 p.s.i.
Yield point	6,000 p.s.i.
Elongation	52 per cent

Copper tubing is obtainable in many sizes and wall thicknesses. Owing to greater strength qualities a copper-silicon-bronze alloy tubing is replacing the pure copper tubing to some extent. It has a U.T.S. of 50,000 p.s.i. with an elongation of 35 per cent. This alloy is annealed at a temperature of 1000 to 1100°F., followed by quenching.

2. *Brass* is a copper-zinc alloy. Some of these alloys have small amounts of aluminum, iron, lead, manganese, magnesium, nickel, phosphorus, or tin. Brass with a zinc content ranging up to 37 per cent is a ductile, work-hardened alloy that cannot be heat treated. Alloys containing a greater percentage of zinc can be heat treated. Two of the more generally used brasses are naval brass and red brass.

Naval brass, or S.A.E. 73, is sometimes called *Tobin Bronze*. This material is not so strong as other materials, but because of machining qualities it is used extensively for turnbuckle barrels, screws, nuts, bolts, and studs.

CHEMICAL COMPOSITION

Copper	59.0 to 62.0 per cent
Tin	0.5 to 1.5 per cent
Iron (maximum)	0.10 per cent
Lead (maximum)	0.30 per cent
Impurities	0.10 per cent
Zinc	Remainder

Sheets and Bars

U.T.S	54,000 to 67,000 p.s.i.
Yield point	45,000 to 20,000 p.s.i.
Elongation	15 to 30 per cent

Because of its good casting qualities and machining qualities, red brass (S.A.E. 40) is used for fuel- and oil-line fittings.

CHEMICAL COMPOSITION

	Per Cent
Copper	84.0 to 86.0
Tin	4.0 to 6.0
Lead	4.0 to 6.0
Zinc	4.0 to 6.0
Iron (maximum)	0.25
Phosphorus (maximum)	0.75
Antimony (maximum)	0.25
Impurities (maximum)	0.15

Physical Properties—Castings

U.T.S.	26,000 p.s.i.
Yield point	12,000 p.s.i.
Elongation	15 per cent

3. *Bronze* is a copper-tin alloy with a small percentage of other alloys. The most extensively used bronze is phosphor bronze (S.A.E. 77), which can be obtained in the form of rod, bar, strip, sheet, and wire. It is widely used for springs and in cast form for gears and bushings. The cast material differs slightly in chemical properties from the rod and sheet. The U.T.S. of the cast is only 40,000 p.s.i., with a 20 per cent elongation.

CHEMICAL COMPOSITION

Copper (minimum) } Tin (minimum) }	Remainder
Phosphorus	0.03 to 0.35 per cent
Lead (maximum)	0.05 per cent
Iron (maximum)	0.10 per cent
Antimony (maximum)	0.01 per cent
Zinc (maximum)	0.03 per cent

Nickel Alloys. 1. *Inconel* is a nickel-chromium nonmagnetic nonferrous alloy. It is thought by many that Inconel is more or less the same as 18-8, but *this is not true.* Inconel is composed of the following materials:

	Per Cent
Nickel	78
Chromium	15.5
Iron	6.9
Manganese	0.35
Carbon	0.08
Copper	0.4
Silver	0.35

It has the following properties:

Sheet	U.T.S., p.s.i.	Yield strength, p.s.i.
Annealed	80,000 to 95,000	30,000 to 40,000
Full-hard	125,000	100,000

The undesirable results obtained in 18-8 steels after welding are not present in Inconel. It also has higher corrosion-resistant qualities at high temperatures. For this reason Inconel is widely used for exhaust stacks. It welds, solders, brazes, and works easily, but weighs more than 18-8 steel. When welding Inconel, one must use Inconel welding rod and flux.

2. *Monel,* a high nickel-copper alloy, has high strength and excellent resistance to corrosion. It can be hardened, not by heat treatment, but only by cold working.

The chemical composition for wrought monel products is as follows:

	Per Cent
Nickel	68.0
Copper	29.0
Iron	1.5
Manganese	1.1
Silicon	0.1
Carbon	0.15

Spring wire has a higher manganese content, and castings have a higher silicon content.

PHYSICAL PROPERTIES
Modulus of elasticity tension, 25,000,000 to 26,000,000

	U.T.S., p.s.i.	Yield point, p.s.i.	Elongation, per cent
Sheet and strip:			
Annealed	65,000 to 80,000	25,000 to 35,000	40 to 25
Full hard	100,000 to 120,000	90,000 to 110,000	8 to 2
Tubing:			
Annealed	65,000 to 80,000	25,000 to 35,000	35 to 25
As drawn	90,000 to 105,000	60,000 to 75,000	20 to 15
Rod and bar:			
Annealed	70,000 to 85,000	25,000 to 35,000	50 to 35
As drawn	85,000 to 125,000	60,000 to 95,000	35 to 15
Hot rolled	80,000 to 95,000	50,000 to 65,000	45 to 30

The magnetic properties of monel vary with the temperature and treatment.

Open annealing of this material is done by heating to 1700°F., holding for 3 to 7 min., and quenching in a 2 per cent alcohol-water solution.

For excessive working, it is necessary to anneal frequently. Sheet monel can be bent about a radius equal to one thickness of the material. The cold ductility of the metal is demonstrated by its suitability for making the sylphon type of bellows and corrugated flexible tubing.

Monel can easily be machined, welded (gas or arc), brazed, and soldered.

3. *K Monel.*—This form of monel is a nonferrous alloy composed mainly of nickel, copper, and aluminum. Because of its corrosion resistance, it is used for gears and chains on amphibian planes. This metal is nonmagnetic and can be heat treated.

The approximate composition of K monel is as follows:

	Per Cent
Nickel	64.0
Copper	30.0
Aluminum	3.45
Carbon	0.2
Iron	1.5
Manganese	0.5
Silicon	0.2

This metal is obtainable in five different hardness grades, with U.T.S. varying from 120,000 to 175,000 p.s.i. and a yield point from 80,000 to 130,000 p.s.i.

Grade A is the only grade that can be easily worked. However, all grades can be machined, welded, brazed, and soldered without much trouble. Special flux is necessary for the welding.

Protective Finishes

Protective finishes used in aircraft may be divided into two types: painting and plating.

Paint.—Paints are widely used in aircraft, not only for decorative purposes but as a protective coating to prevent rust, corro-

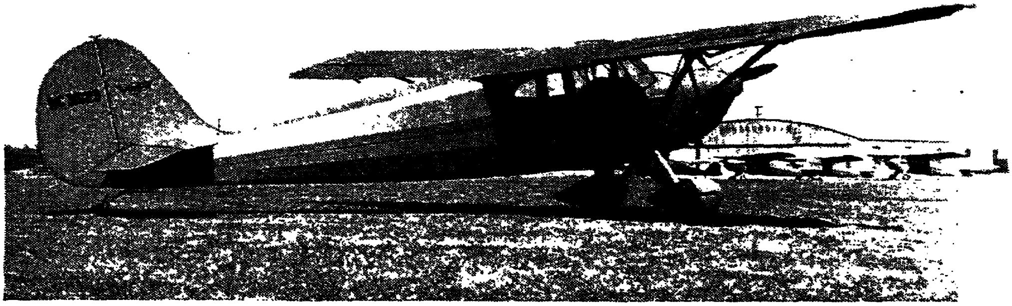


Fig. 198.—Aeronca Chief, a fabric-covered steel tubular airplane. The fabric has been doped with nitrate dope.

sion, and rot. Dope is applied to fabric to give a taut surface as well as greater life. Oil base, cellulose base, and synthetic base are the three kinds of paint in general use. The characteristics of each of these should be known before they are applied, for they do not mix well.

Oil-base paint is the type to which the paints commonly referred to as house paint, inside and outside wall paint, varnish, and enamel belong. Two of the oils used in the manufacture of these paints are linseed and tung oil. Possible thinners are turpentine and benzine. These paints are not widely used in aircraft because they require too much time for drying. However, varnish is extensively used on wood structure as a protective

coating and as a dope-proof paint. Linseed oil is heated and poured inside welded steel structure to prevent rust.

The *cellulose-base paints* have a base of nitrocellulose or cellulose acetate and are mixed with volatile thinners. They are used as dope to furnish the protective finish for fabric. They dry quickly, giving a high-luster taut surface. Cellulose paints must not be applied over oil-base paints as they will raise the latter. Oil-base paints, however, can be applied over cellulose-base paints.

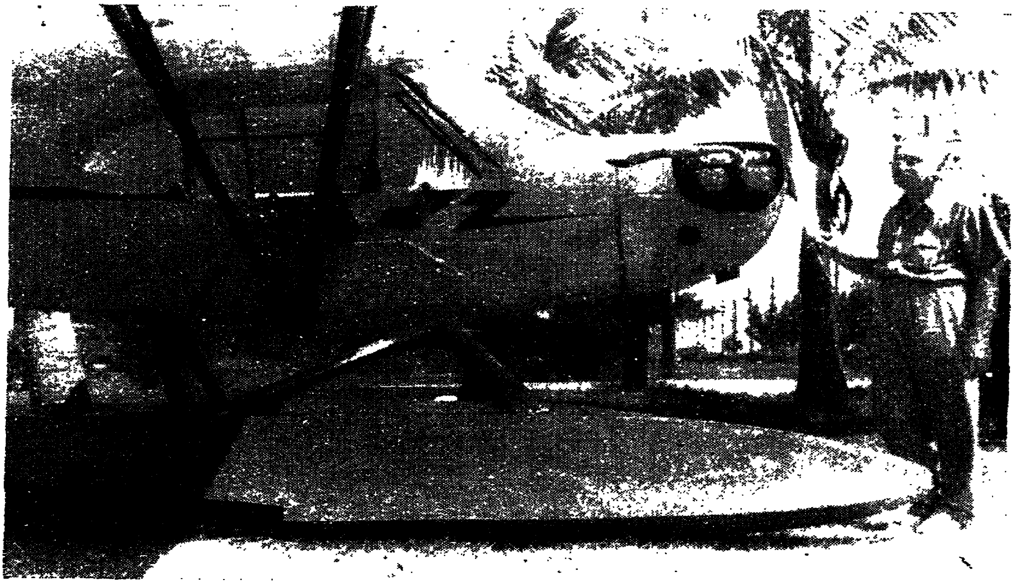


FIG. 199.—Plastic pontoons manufactured by Crosley Marine.

Many household furnishings and automobile parts are painted with quick-drying *synthetic-base* paints and enamels. One of the best-known paints in this class is zinc chromate, a metal primer. Although zinc chromate was intended mainly for use as an aluminum primer, it has almost replaced red oxide, an oil-base primer, as a primer for steel.

Plating.—Plating of metal parts, particularly steel, is widely used to prevent rust or corrosion. Cadmium plating is used for small fittings, bolts, nuts, landing gears, etc. Anodizing is the process of depositing an oxide coating on aluminum to prevent corrosion. With the increased use of Alclad, the use of this process is decreasing.

PLASTICS

Plastics is a new branch of the aeronautical industry that may prove to be very promising. At present, the plastics, extensively used in aircraft can be limited to a few materials, as Pyralin, Bakelite, Micarta, and Formica. However, complete cargo planes and many small units are now being manufactured out of plastic-bonded plywood and fabrics. Should such materials prove satisfactory, their use is unlimited.

Pyralin is a transparent material manufactured from nitrocellulose and camphor. It is used for windshields, windows, etc.

SOUNDPROOFING

With the trend of modern aviation toward added comfort, the manufacturer has made every effort to reduce undesirable noises in the cabin and cockpit of the plane. This has been done by mounting the engine on shock mounts to help eliminate vibration, by reinforcing the structure to help eliminate oil canning, and by installing noise-absorption materials on the cabin and cockpit walls. Some of these materials are kapok, cotton matting, and fiber glass.

CHAPTER V

HYDRAULICS

HYDRAULICS—GENERAL

Hydraulics is the study of the mechanics of fluid transfer, or fluid flow. Because of two well-known principles, fluid transfer with high efficiency is possible. These principles are as follows:

1. Fluid is noncompressible.
2. Fluid pressure is transmitted in all directions unchanged in intensity (neglecting head).

Another hydraulic principle that the student should be familiar with is that pressure is due to head.

These three principles can best be explained by several examples:

Fluid Is Noncompressible

To demonstrate this, fill a bottle full of water and try to place a cork in the bottle without spilling any of the water. This will be impossible because the water will not compress.

Pressure Due to Head

If a cube, 1 in. on each side and weighing 0.1 lb., is placed on a scale, it would read 0.1 lb. As the area of any face is 1 sq. in., the pressure exerted on the supporting face of the cube is 0.1 p.s.i. If nine additional blocks are placed on top of the first, the scale will read 1 lb., and the force on the bottom block is 1 p.s.i. If a second column of blocks is placed on the scale, the scale will read 2 lb. and yet the weight supported by the bottom face of the lower block will still be 1 p.s.i. On the other hand, if the blocks were placed out flat on the scale, the scale would still read 2 lb. but the force on the supporting faces would now be only 0.1 p.s.i. Therefore, it can be seen that the force exerted on the supporting blocks is due, not necessarily to the number of blocks, but to the height of the blocks.

This principle also holds true in hydraulics. The pressure p per square inch is, due not to the shape of the container, but only to the weight of the fluid per cubic inch and the height of the column of fluid. Upon applying this principle to the container in Fig. 200, it can be seen that the fluid pressure per

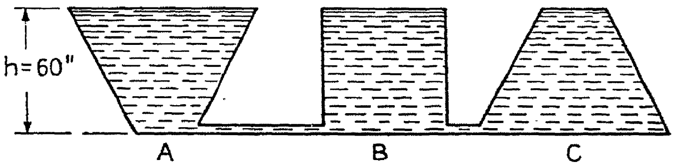


FIG. 200.—Pressure head.

square inch in each is the same. If water weighs 0.036 p.s.i., what will the pressure per square inch be if the water is 60 in. deep?

$$p = hw \tag{59}$$

where p = pressure, p.s.i.
h = head, in.
w = weight, lb. per cu. in.
$p = 60 \times 0.036 = 2.160$ p.s.i.

FLUID-PRESSURE TRANSFER

Fill a thin-walled paper container (Fig. 201) with water, and close it tight except for a small hole in the top. Insert a glass

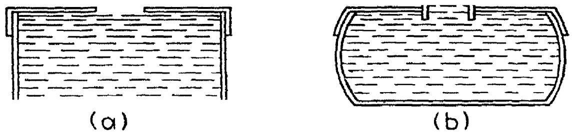


FIG. 201.—Bursting a paper container with hydraulic pressure.

tube in this hole, and fill the tube with water until the container bursts. As the water in the container will not compress, the water must rise in the tube; but as the water rises, the pressure at the bottom of the tube increases, owing to the weight of the water. Since the pressure will be transmitted in all directions, it

finally reaches a point at which the container will burst. The force at the bottom of the tube is equal to the weight of the column of water in the tube, and the force per square inch will be the weight divided by the area of the tube.

$$F = W = Ap \tag{60}$$

where F = force, lb.
W = weight of water, lb.
A = cross-sectional area of tube, sq. in.
p = hydraulic pressure, p.s.i. (always perpendicular to surface)

The pressure against the wall will be the area of the container wall multiplied by the hydraulic pressure.

$$F_2 = A_2p \tag{61}$$

where F_2 = force on wall
A_2 = area of container wall

Therefore, if $W = 1$ lb, $A_1 = 0.5$ sq. in., and $A_2 = 5$ sq. in., the following will hold for F_2:

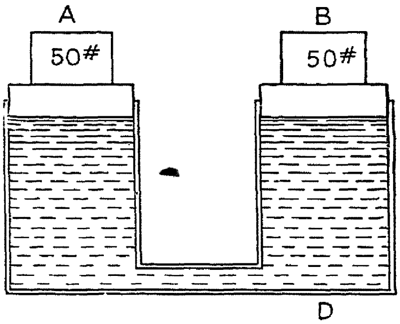


Fig. 202.

$$F = W = Ap$$
$$1 = 0.5 \times p$$
$$p = \frac{1}{0.5} = 2 \text{ p.s.i.}$$
$$F_2 = A_2p = 5 \times 2 = 10 \text{ lb.}$$

Another example is shown in Fig. 202. Here two cylinders A and B are filled with water. The area of each is 5 sq. in., and each has a piston supporting a 50-lb. weight. The hydraulic pressure as for the previous example is expressed in pounds per square inch. This pressure just below piston A and B will be found by dividing the 50 lb. by 5 sq. in. and is equal to 10 p.s.i.

$$W = F = Ap$$
$$50 = 5p$$
$$p = 10 \text{ p.s.i.}$$

where W = 50 lb.
A = 5 sq. in.

Since the area is the same for both pistons, p for both must be the same. Therefore, each piston will remain stationary. Neglecting the weight of the fluid, p at points C and D will also be the same, or 10 p.s.i.

In Fig. 203, cylinder A has a cross-sectional area of 5 sq. in., while cylinder B has a cross-sectional area of 1 sq. in. Therefore, if the weight on piston A is 50 lb., the weight on piston B must be 10 lb. to prevent piston movement. Also, neglecting the weight of the head of fluid, the pressure per square inch will be the same at points C and D, or 10 p.s.i.

For A
$$F = Ap$$
$$50 = 5p$$
$$p = 10 \text{ p.s.i.}$$

where $F = 50$ lb.
$A = 5$ sq. in.

For B
$$10 = 1p$$
$$p = 10 \text{ p.s.i.}$$

where $F = 10$ lb.
$A = 1$ sq. in.

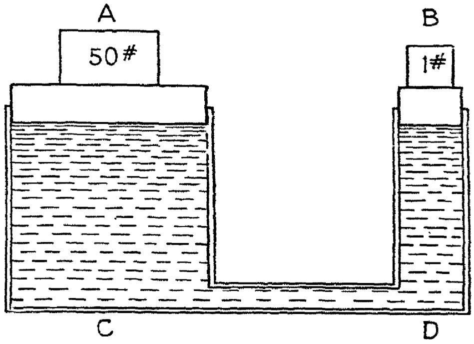


FIG. 203.

Should an external force be applied to piston B, p for that piston will increase and B will go down. Since the system is closed, piston A will rise as B goes down. Piston A will rise one-fifth the distance piston B goes down, because piston A is five times as large as piston B. That is, piston area times travel must equal a constant, or

$$d_A A_A = d_B A_B = C \tag{62}$$

where A_B = area of piston B, sq. in.
d_B = distance piston B travels, in.
A_A = area of piston A, sq. in.
d_A = lift of piston B, in.
C = constant

Since piston B must travel farther than piston A in the same time, the velocity of piston B must be greater than the velocity of piston A. This relation varies as the equation above, and

$$V_A A_A = V_B A_B = C \tag{63}$$

where V_B = velocity of piston B
V_A = velocity of piston A
C = constant

These principles are employed in the simple hydraulic jack and operating strut. The simple jack is shown in Fig. 204. The handle operates pump A up and down. On the upstroke, fluid is taken from the reservoir through check valve C to fill cylinder A. On the downstroke, fluid pressure against ball C closes it and opens ball check E, allowing the fluid to flow into chamber B. This incoming fluid raises piston B. On the upstroke, the force exerted on piston B by the weight W forces fluid against ball

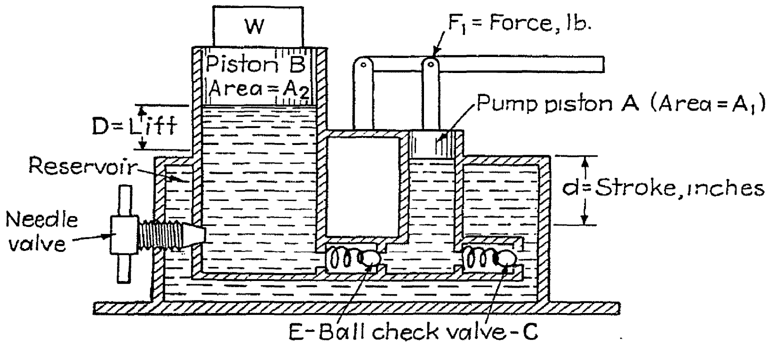


Fig. 204.—Simple jack.

check E, closing it. At the same time, fluid is drawn in from the reservoir past ball check C, and the cycle repeats itself until weight W is raised to the deserved height or piston B reaches the top of the cylinder. The maximum load to be lifted is the area of piston B times the maximum pressure per square inch p, or

For piston A of pump $\qquad F_1 = A_1 p \qquad (64)$
where F = force, lb.

or
$$p = \frac{F_1}{A_1} \text{ in p.s.i.} \qquad (65)$$

For piston B
$$F_2 = W_{\max} = A_2 p$$
$$W_{\max} = \frac{A_2 \times F_1}{A_1} \text{ in lb.} \qquad (66)$$

The distance D that piston B rises each stroke d, of pump A is

$$A_2 D = d A_1$$

$$D = \frac{dA_1}{A_2} \text{ in inches.}$$

To lower piston B, open the needle valve and allow the fluid in cylinder B to return to the reservoir.

Owing to high efficiency, ease of installation, light weight, and minimum maintenance required, hydraulics are widely used by aircraft manufacturers to operate remote units. Some of these units are wheel-retracting struts, bomb-door retracting struts, brake power valves, wing-flap operating struts, and control-surface boosters.

Small planes employ simple systems, operating one or two items by means of a hand pump. The modern transport and long-range bomber have complicated systems, employing engine-driven pumps, hand pumps, pressure accumulators, etc.

Simple System

Schematic diagrams, showing a modified form of two hydraulic systems, one simple and one complex, are given in Figs. 205 and 209. Figure 205 shows the operation of only one ram by a hand pump. The strut could be either a landing-gear strut or a flat strut. The supply tank supplies fluid to the hand pump. A typical supply tank is shown in Fig. 218. A schematic drawing of the hand pump is given in Fig. 206. On the first stroke to the left, fluid is drawn in past the "in" ball check valve to the "in" chamber. The first stroke to the right closes the in ball check valve and opens the ball check in the piston, forcing the fluid into the "out" chamber. The second stroke to the left closes the piston ball check and opens the "out" and "in" ball checks, forcing the fluid in the pump out to the system and at the same time drawing fluid in from the supply tank. The cycle is then repeated.

If the shaft of the piston on the "out" side is increased until its volume is one-half the volume of the "in" side, the hand pump becomes a double-acting pump. This can easily be seen, because twice as much fluid is drawn "in" as can be accommodated by the "out" side. Therefore, one-half the "in" volume must be delivered to the system on each stroke to the right. The other half is delivered to the system on each stroke to the

left. This does not increase the volume of output of the pump but does give more even fluid flow.

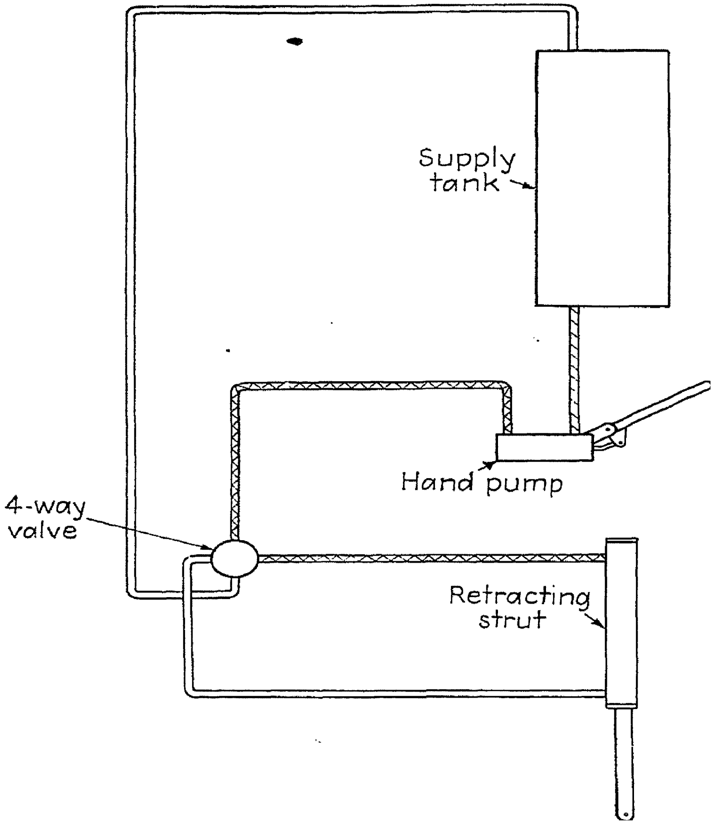


FIG. 205.—A schematic simple hydraulic system.

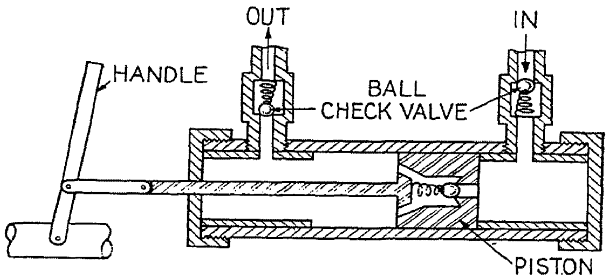


FIG. 206.—Simple hand pump. *(Courtesy of Eastern Air Lines, Inc.)*

From the hand pump the fluid goes through the four-way valve to the strut. A cross-section of this valve is given in

Fig. 207, and a cross-section of the strut is given in Figure 208. Since the strut must work both ways, one side of the strut must return fluid to the tank when the other side is receiving fluid under pressure from the hand pump. Fluid entering port 1 of the four-way valve (top view) goes out port 2 to the down side of the strut. Returning fluid from the up side of the strut enters port 3 and goes out to the supply tank by port 4. After the strut has been extended all the way the four-way valve is rotated

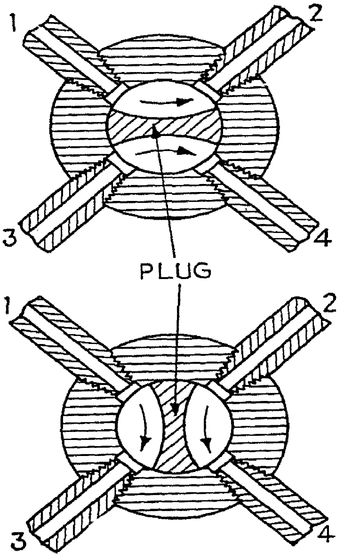


FIG. 207.—Four-way plug valve. (*Courtesy of Eastern Air Lines, Inc.*)

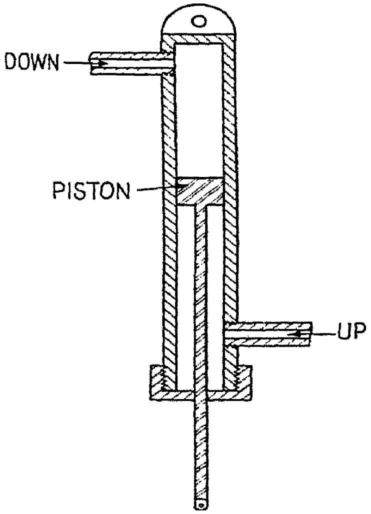


FIG. 208.—Schematic retracting stand. (*Courtesy of Eastern Air Lines, Inc.*)

to take the second position shown. Pressure from the pump now passes out port 3 to the up side of the strut. The returning fluid from the down side returns through ports 2 and 4 to the supply tank.

COMPLEX SYSTEM

Figure 209 shows a more complicated hydraulic system employing the engine pump and the pressure accumulator (pressure tank). The engine pump makes possible the operation of larger units at greater speed than is permissible with the hand pump. The pressure accumulator permits the storage of a quantity of fluid under pressure, so that, when it becomes necessary to

operate the landing gear and flaps, the quantity of fluid required by this system can be supplied at once, preventing a lag in

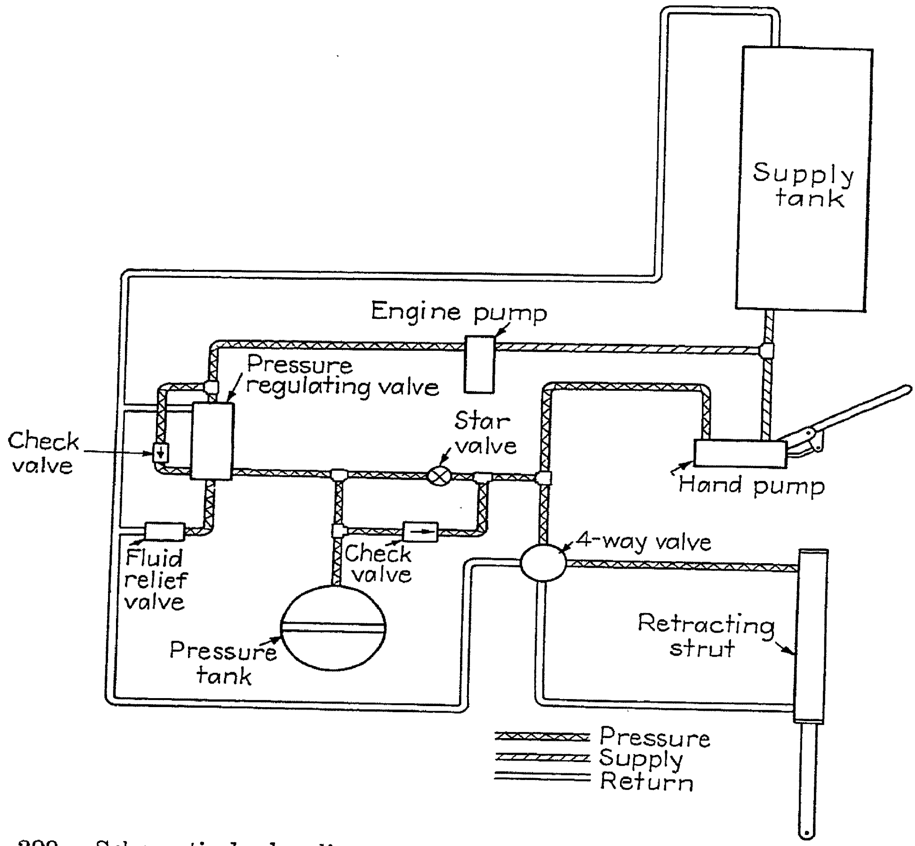


FIG. 209.—Schematic hydraulic system. (*Courtesy of Eastern Air Lines, Inc.*)

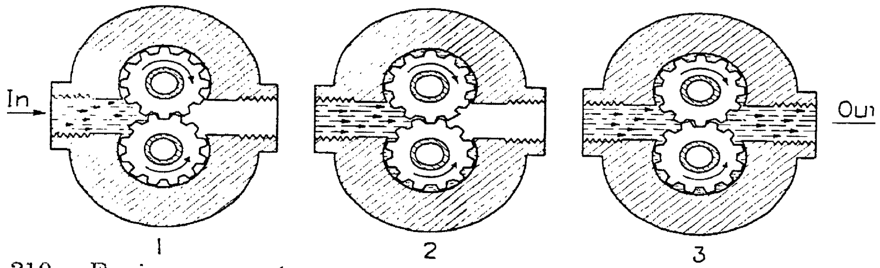


FIG. 210.—Engine pump (gear type). (*Courtesy of Eastern Air Lines, Inc.*)

operation. It also permits the storage of fluid under pressure for operation of brakes and flaps without operating the hand pump

while the ship is on the ground. This may be while the engines are running at too low a speed to furnish pressure or are not running. A cross-section of a gear type of engine-driven pump and a fluid pressure tank is given in Figs. 210 and 211. When the air under pressure is delivering fluid to the system, the diaphragm takes position 1. When the gear pump has built up pressure in the tank, the diaphragm takes position 2.

Fluid from the supply tank passes through the engine pump to the pressure regulating valve (cross-section given in Fig. 212). Fluid under pressure forces the ball check down on the seat, causing the fluid to by-pass by way of the T to the rear of the

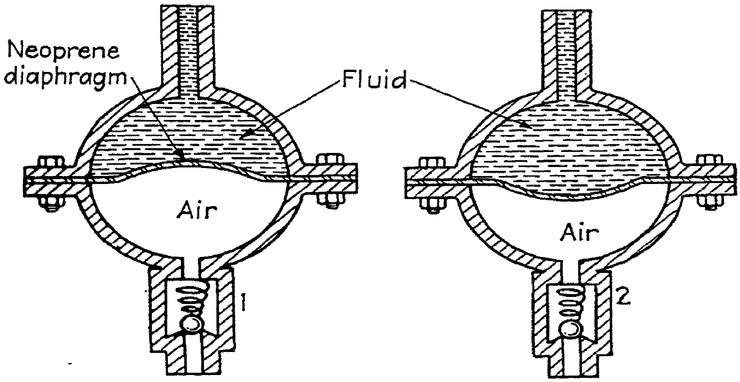


FIG. 211.—Spherical pressure tank. (*Courtesy of Eastern Air Lines, Inc.*)

valve and out to the system. Since the fluid relief valve prevents the fluid from returning to the supply tank, pressure is built up in the pressure tank. When the pressure in the system builds up to the relief pressure of the pressure regulating valve, the piston in the bottom end of the valve collapses the spring, forcing the ball off the seat. Fluid under pressure from the engine pump now returns to the supply tank. Pressure in the system is held there by the check valve to the left of the pressure-regulating valve and the fluid relief valve. When the engine pump is being used, the star valve is kept closed. With this valve closed and the ball check valve in the line to the pressure tank, excessive pressures built up in the system owing to heat cannot be relieved. Therefore, a No. 80 hole is drilled in the star valve to allow such pressure to seep back to the fluid relief valve. When the pressure reaches the maximum permissible

for the system (1,000 p.s.i. for DC-3), the fluid relief valve opens and the fluid returns to the supply tank. [The fluid relief valve is sometimes called the *pressure relief valve* (see Figure 213.)]

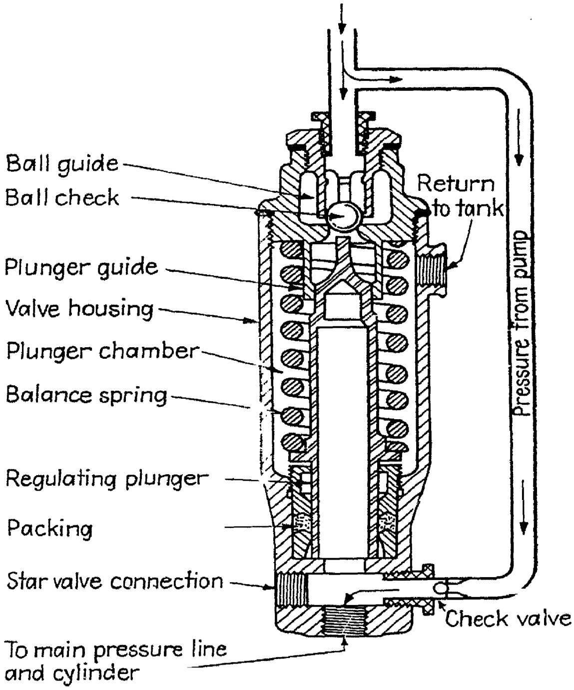


FIG. 212.—Pressure-regulating valve. (*Courtesy of Douglas Aircraft Co.*)

When the four-way valve is operated to allow strut movement, fluid is furnished by the pressure tank. As the system fluid

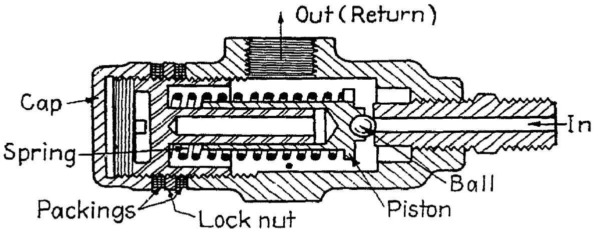


FIG. 213.—Fluid relief valve. (*Courtesy of Douglas Aircraft Co.*)

pressure falls because of this movement, the piston in the pressure regulator valve is forced to the right by the spring closing the return line at the ball check. The pump now furnishes fluid

under pressure to the system. Fluid from the return side of the strut returns to the supply tank the same way as the fluid in the system of Fig. 205.

If it is necessary to operate the strut with the hand pump because of engine-pump failure or for other reasons, the star valve remains closed. If it is necessary to build up pressure in the system with the hand pump (pressure accumulator tank), the star valve is opened.

If more than one unit is required (flap struts, brakes, etc.), additional four-way valves can be placed in the pressure supply line of either system 1 or system 2.

If two engine gear pumps are desired, a four-way engine selector valve can be placed between the engine pumps and the pressure regulating valve. In this case the pump not in use merely circulates fluid between the pump and tank under little or no pressure.

Two physical properties of fluids that must be considered in selecting fluid for hydraulic systems are the effect of severe cold weather and the effect of very hot weather on the fluid.

Cold weather, through which airplanes must fly daily in winter, tends to freeze or restrict the flow of fluids. If this restriction of flow becomes too great, the hydraulic system becomes useless. Therefore, a fluid whose viscosity will remain well within the desired limits of safe operation even in severe cold weather is desired. To aid in high-altitude flying some hydraulic units employ electrical heating units to heat the fluid.

As the temperature of the fluid is increased above normal, the rate of flow through a restriction will increase. At the same time the fluid will expand and may build up excessive pressures in small units, resulting in damage to them. To help prevent this, a fluid of small thermal expansion at reasonable temperatures is used.

The two fluids most commonly used are Lockheed No. 21 and Sperry Servo oil. The Lockheed No. 21 is a vegetable oil, and Sperry Servo oil is a mineral oil. The two oils are not always interchangeable, and the manufacturer must be consulted before any change is made. Under no circumstances should the two be mixed. The change in fluid may also require a change in packings and hose. Rubber packings are recommended with

Lockheed No. 21, and Neoprene or Thiokol packings are recommended with Servo oil. Only Sperry Servo oil can be used in systems employing Sperry automatic pilots.

Brakes

The piston self-energizing brake, the multidisk brake, and the expander tube brake are the three types most commonly used.

The self-energizing brake is very similar to the brakes used on automobiles and employs two brake shoes operated by a hydraulic piston. Springs return the shoes to their normal position when the fluid pressure is removed (see Fig. 214*a*).

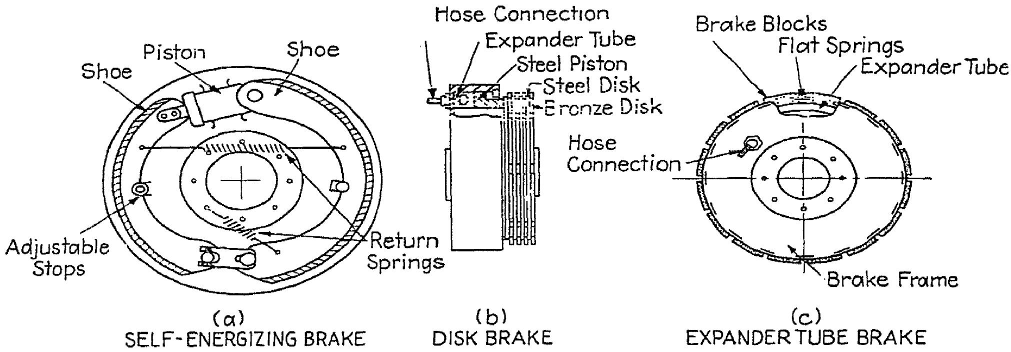


Fig. 214.—Schematic drawing of three types of brake.

The disk type of brake is a multidisk clutch with the alternate bronze disks rotating with the wheel and alternate steel disks remaining stationary. Fluid pressure expands a tube, forcing a ring piston against the outer disk. Return springs return the disks to their proper position when the pressure is removed, as in Fig. 214*b*.

The expansion tube brake has a Neoprene tube stretched around the brake frame. On top of this, brake shoes in small segments are placed. These shoes extend entirely around the brake assembly and are held in place by flat springs. As the brake tube is expanded, the blocks move out around the entire circumference of the frame, giving almost 360° breakage. When fluid pressure is removed, the clip springs return the blocks to the normal position, as in Fig. 214*c*.

Brakes may be operated by separate brake cylinders attached to each brake pedal; by a master cylinder and by a differentiating cylinder directing the fluid flow; or by the accumulator system

in which the operation of a brake power valve by the brake pedals directs pressure from the accumulator to the proper wheel. The latter system is very popular for large aircraft.

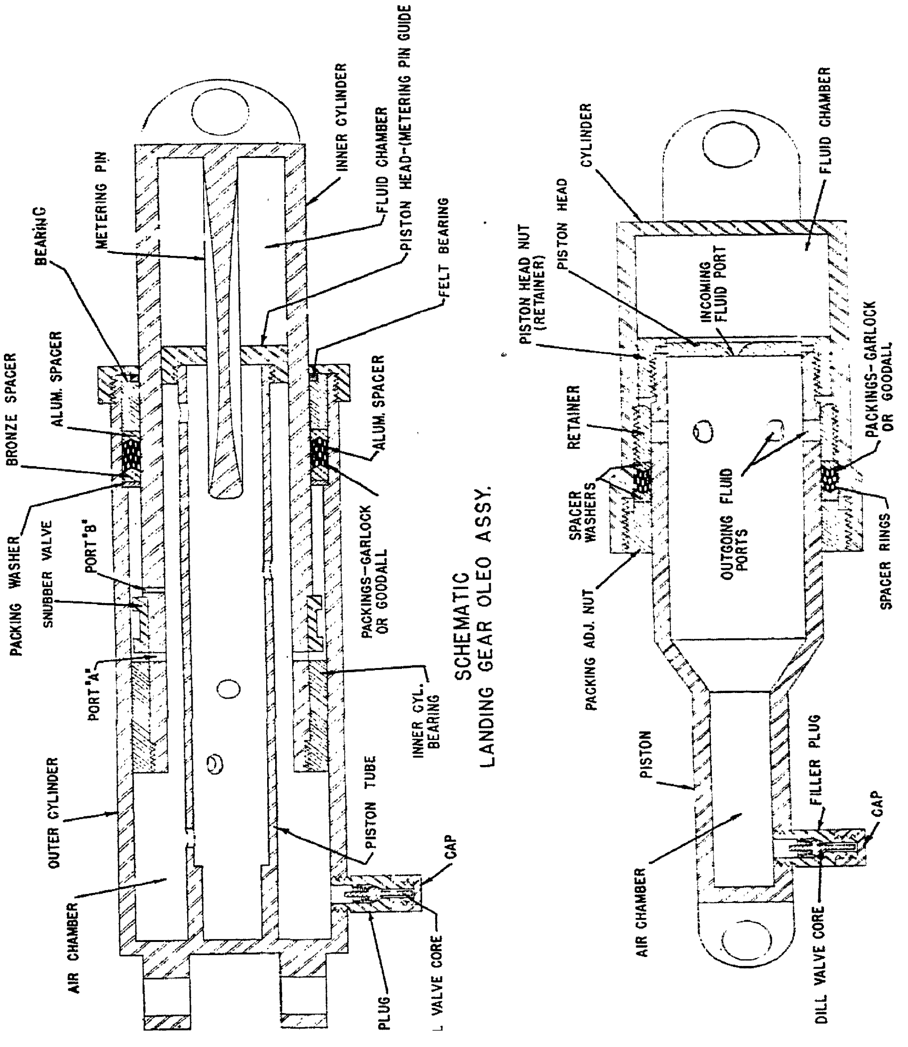


FIG. 215.—Schematic tail-wheel shock-absorber assembly. (*Courtesy of Eastern Air Lines, Inc.*)

LANDING-GEAR OLEO

When the airplane first touches the ground, shock-absorbing units must dissipate the kinetic energy of the plane. The early

airplanes employed rubber shock cords. These were replaced by rubber disks and later by the oleo strut. The two first methods are still in use in the low-price field.

A cross-section of two oleo struts is given in Fig. 215. The upper strut has oil confined in the lower part of the *inner cylinder*. Compressed air is in the *air chamber* and the *piston tube*. When the wheel touches the ground, fluid is forced around the *metering pin* and out the holes in the *piston tube*. The compressed air is forced from the top of the cylinder out *port A*. When the ship bounces, the *snubber valve* moves up, closing port *A* as the inner cylinder moves down. This forces all the air back through the smaller *port B*. A snubbing action is thus created to prevent severe bouncing. While the ship is taxiing, the compressed air cushions any small shock. Severe shock caused by rough ground causes operation of the strut.

Packings

Safe operation of both shock and operating struts depends on the condition of the packing. If the packing is scored upon

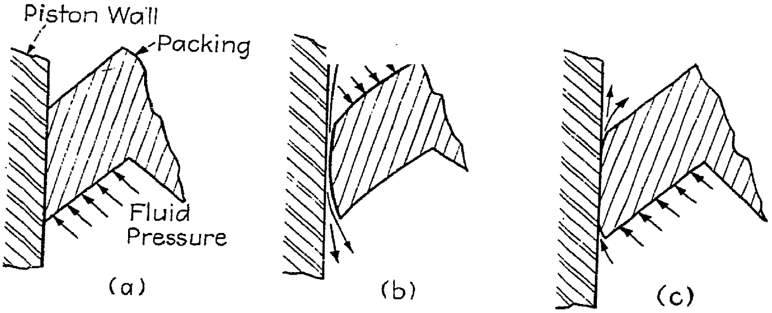


Fig. 216.—Packing under pressure.

installation or by use, the unit will eventually fail. Since all packings are made from a semisoft material, damage can easily result if care is not exercised in overhauling units.

As stated earlier in the chapter, hydraulic pressure acts perpendicular to the surface. Therefore, when fluid pressure is exerted against the packing (Fig. 216*a*), the shape of the packing causes the fluid to force the packing against the cylinder wall, preventing leaks.

If pressure is placed against the back side of the packing (Fig. 216*b*), the fluid will force the packing away from the cylinder and

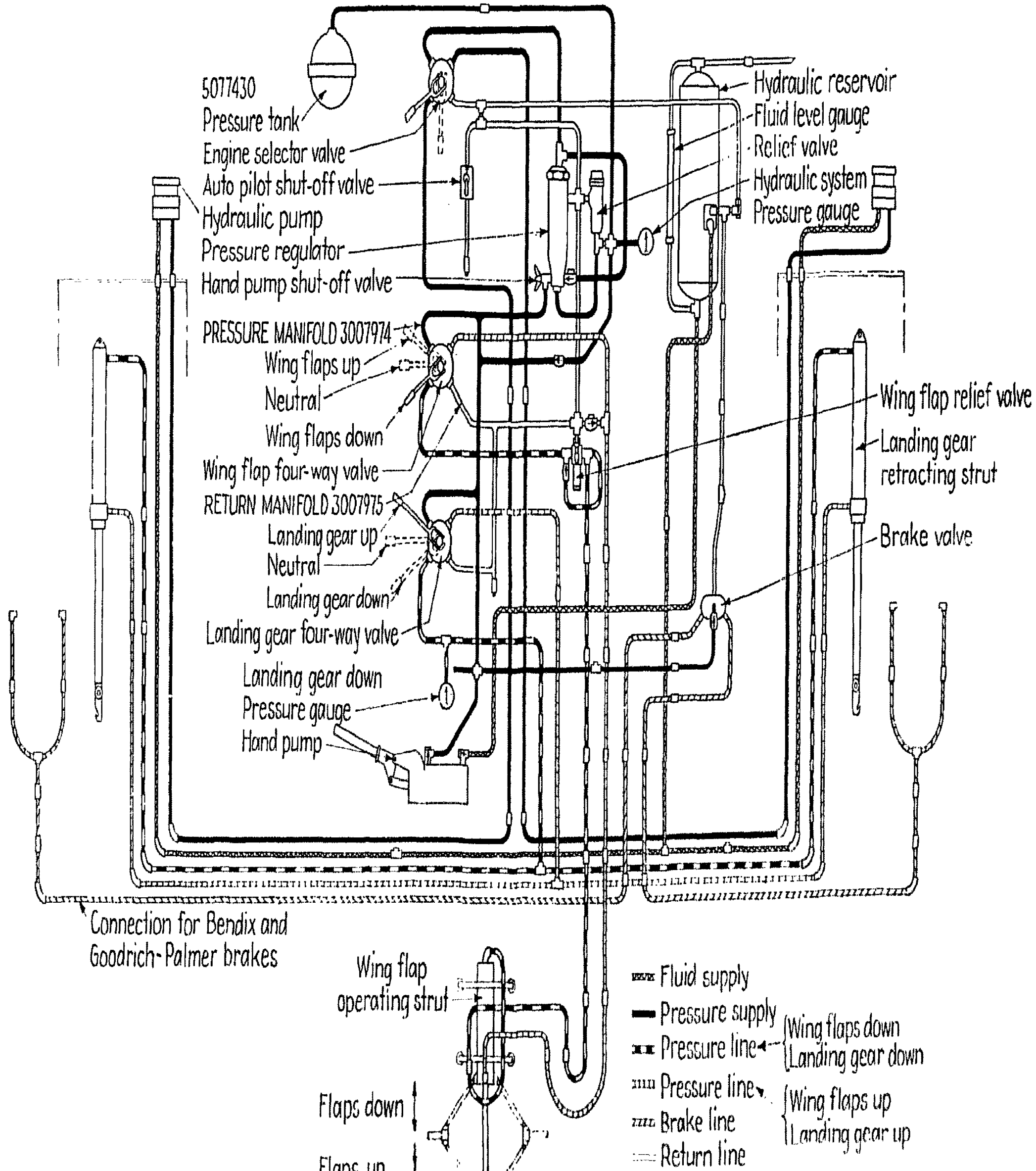


FIG. 217.—Schematic hydraulic system for a Douglas DC-3.

piston wall, allowing the fluid to leak by. To overcome this, two groups of packing facing in opposite directions are always installed on pistons (Fig. 228).

If the sharp edges of the packing are damaged (Fig. 216*c*), fluid leaks will result. Edges destroyed by handling can be restored by the light use of sandpaper if great care is exercised.

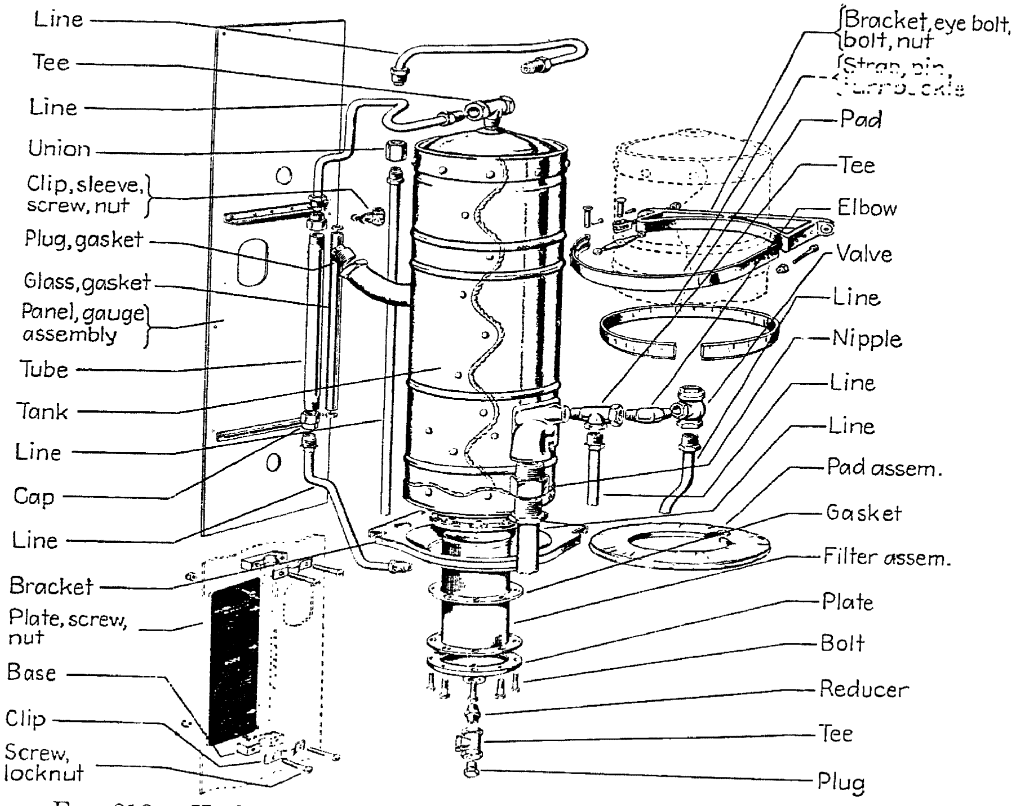


FIG. 218.—Hydraulic supply tank for Douglas DC-3. Panel assembly.

Because these sharp edges eat away under normal operation of the unit, several packings are placed together to give greater service life (Fig. 228).

A small amount of seepage always exists. This is normal and serves to lubricate the piston and the cylinder.

New packings should always be soaked in the proper fluid a few minutes before installation to soften and lubricate the material. All threads over which the packing must pass should

be covered with a packing guard of shim stock. Packings should never be tightened excessively, for this squeezes the packing out of shape, induces excessive drag, and reduces service life.

DOUGLAS DC-3 HYDRAULIC SYSTEM

General

The Douglas hydraulic system is of the accumulator type (Fig. 217). Fluid pressure is supplied by two Pesco engine-

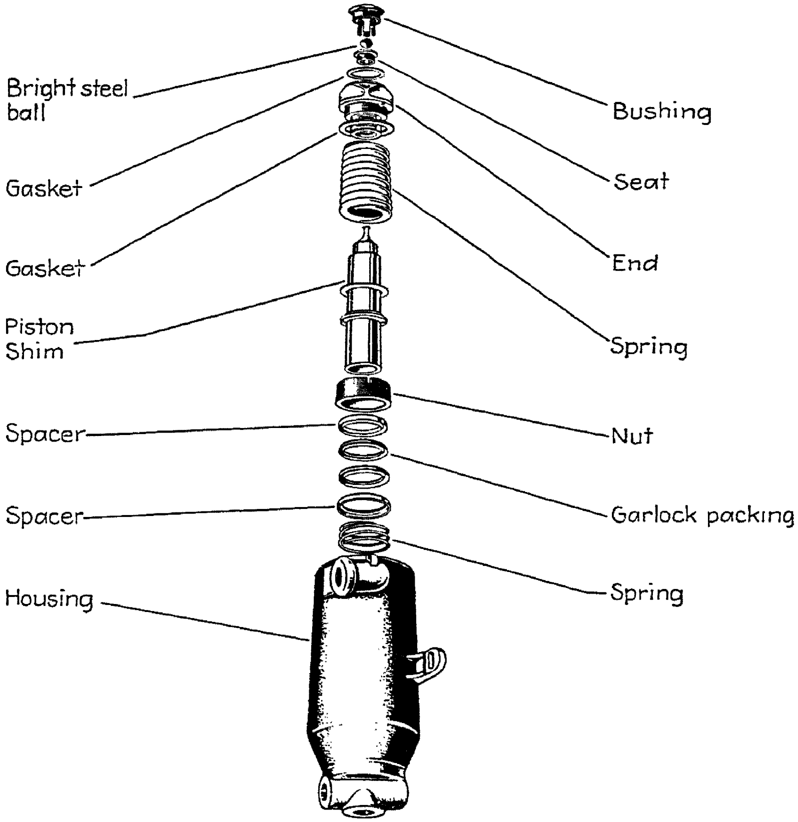


Fig. 219.—Valve assembly. Hydraulic-pressure regulating. (*Courtesy of Douglas Aircraft Co.*)

driven gear pumps (one attached to each engine). Only one of these pumps is used at a time; the other pump circulates fluid from and to the hydraulic supply tank.

The main units of the hydraulic control panel, accessible to captain and pilot, and their functions, are as follows:

The hydraulic fluid supply tank supplies hydraulic fluid to the engine-driven pumps and also to the hand-operated pump. A 60-mesh screen is used in the bottom of the tank to prevent

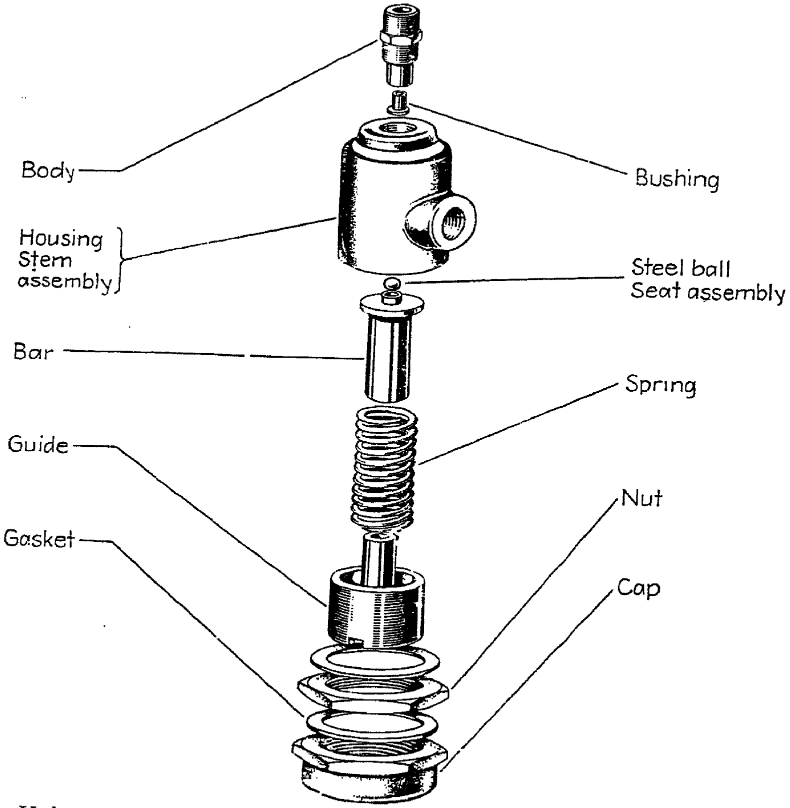


FIG. 220.—Valve assembly. Hydraulic relief. (*Courtesy of Douglas Aircraft Co.*)

foreign matter from entering the system. A sight gauge is attached to the side of the tank for filling purposes (Fig. 218).

The pressure regulating valve regulates the incoming pressure supplied by the engine-driven pump. It will cut out at 800 p.s.i. and cut in at 600 p.s.i. That is, its function is to maintain a system pressure of 600 to 800 p.s.i. while engines are running (Figs. 212 and 219).

Fluid Relief Valve.—In case of regulating-valve failure or ground heat expansion, causing high hydraulic-system pressure,

the pressure relief valve operates at 1,000 p.s.i., relieving the excess pressure (Figs. 213 and 220).

The spherical pressure tank is a diaphragm type used as a storage tank for approximately 1 gal. of hydraulic fluid under pressure (Figs. 211 and 221).

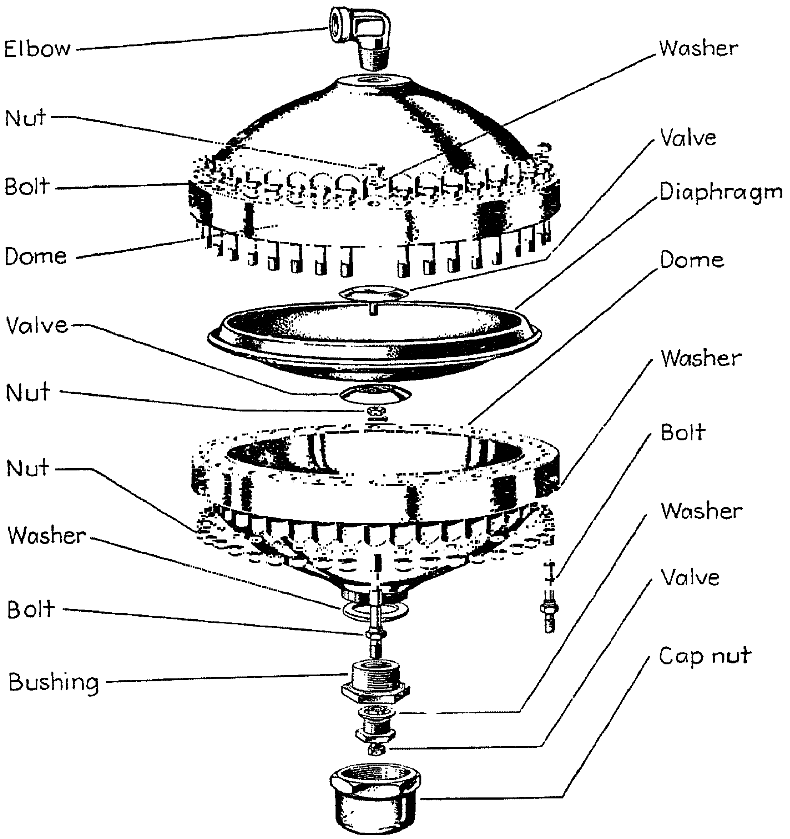


FIG. 221.—Spherical pressure-tank assembly. (*Courtesy of Douglas Aircraft Co.*)

This spherical tank is inflated to 250 p.s.i. air pressure at the lower side of the diaphragm. The hydraulic pressure must be zero while it is being inflated.

Flap Relief Valve (Down Flaps).—If the air loads, due to an air speed above 112 m.p.h. (miles per hour), produce a back pressure on the wing-flap operating cylinder greater than 390 p.s.i., the relief valve will operate, allowing the flaps to rise.

Flaps will automatically rise and lower according to back pressure caused by excess speed or wind gusts (Figs. 222 and 223).

The landing-gear selector valve is a plug type of four-way valve; by selecting the "up-gear" or "down-gear" position, it supplies hydraulic fluid under pressure to one side of the landing-gear retracting strut and allows the fluid without pressure to return to the supply tank from the other side of the strut. The

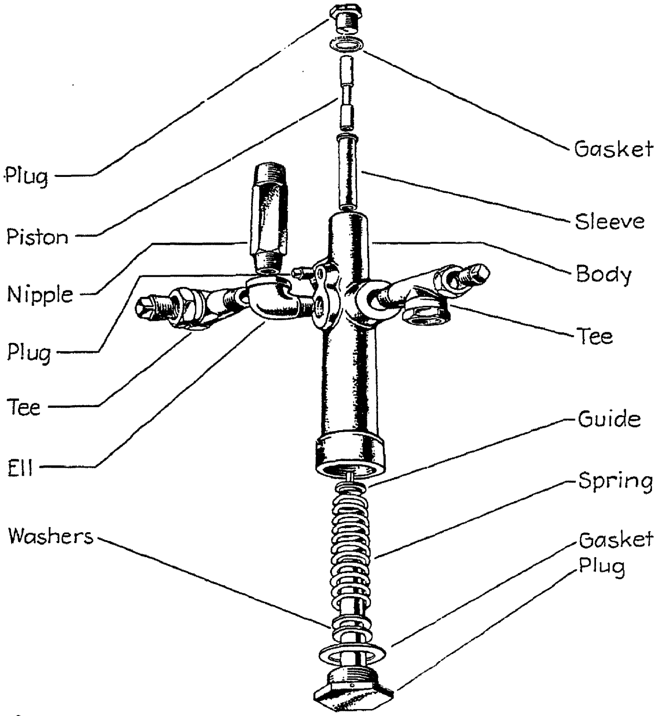


FIG. 222.—Valve assembly. Flap relief. *(Courtesy of Douglas Aircraft Co.)*

position selected determines the direction of flow of the fluid (Figs. 207 and 224).

This valve also has a neutral position; when this is selected, it will stop all fluid flow to the strut, thus locking the strut.

The wing-flap selector valve is the same type of valve as that used for the landing gear. Its purpose is to raise or lower the flaps or lock them in any intermediate position desired (Figs. 207 and 224).

The engine selector valve is the same type of valve as that used for the landing gear. This valve has a "left-engine" and "right-

engine" position. By selecting either position, it supplies pressure to the hydraulic system from the engine-driven pump selected and allows the other pump to circulate fluid from and to the fluid supply tank (Figs. 207 and 224).

The hydraulic hand pump is used to supply emergency hydraulic pressure to the system or to supply pressure when the engines are not running, as in servicing ships on the ground. To operate units with the hand pump, the star valve in the center of the hydraulic panel is closed, the position of the unit desired is

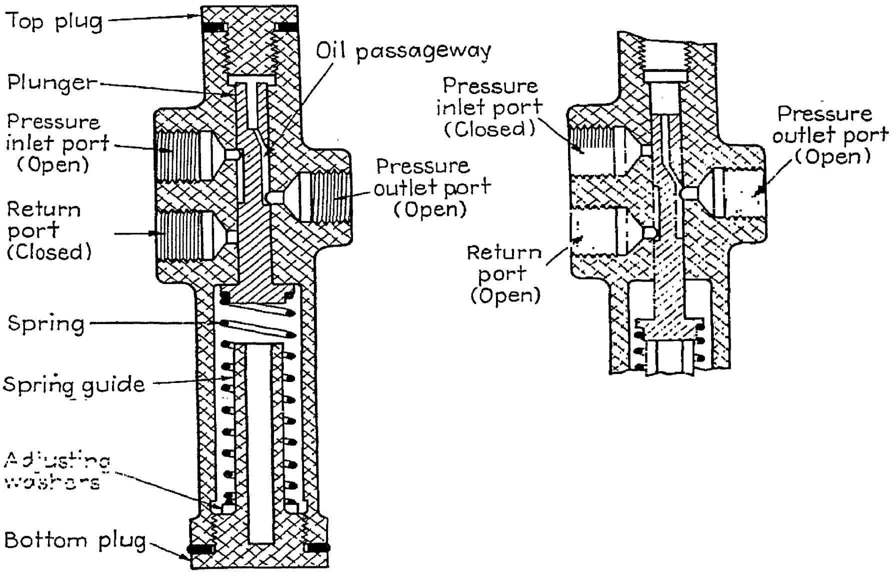


FIG. 223.—Wing-flap relief valve, DC-3. (*Courtesy of Douglas Aircraft Co.*)

selected, and the hand pump is operated. To obtain pressure for the spherical tank, the star valve *is opened* and the hand pump operated (Fig. 206).

Trouble Shooting

Loss of pressure in the hydraulic system is indicated by a drop in gauge pressure on the *hydraulic-system gauge*, which is the rear gauge on the right-hand side of the cockpit.

The cause of this drop can generally be found by checking in one of the following ways:

A. While Ship Is Parked

Spherical Tank for Correct Inflation.—To check the spherical tank for the correct pressure, open the star valve on the panel;

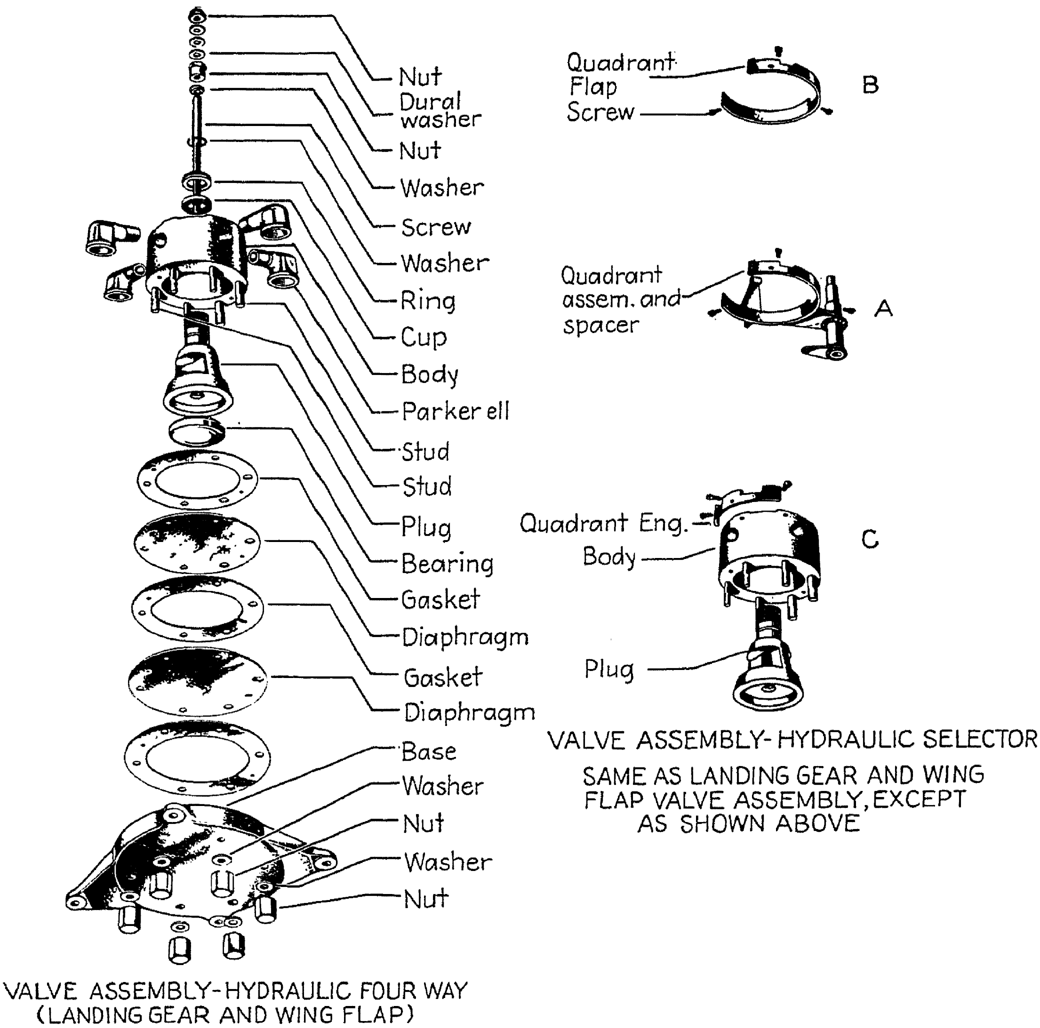


Fig. 224.—(*Courtesy of Douglas Aircraft Co.*)

by means of the hand pump, build up pressure in the system to 500 p.s.i.; and kill the pressure by operating the wing flaps. The last reading on the hydraulic-system gauge before the decided drop to zero should register 250 p.s.i., which is the required air

pressure in the spherical tank. Air inflation should be 250 p.s.i. ±10 lb. The last reading on the main hydraulic gauge indicates the amount of air inflation at the lower side of the spherical tank. The gauges may sometimes vary in their

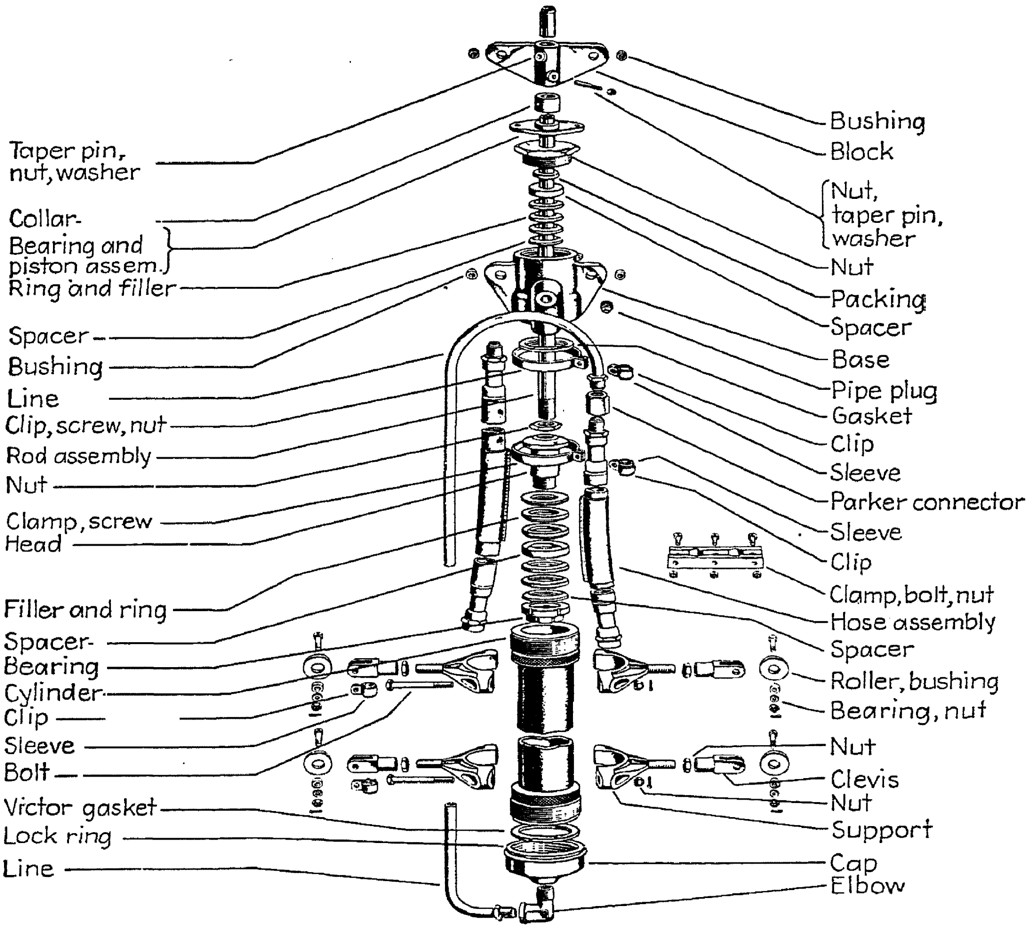


FIG. 225.—Strut assembly. Wing-flap operating. (*Courtesy of Douglas Aircraft Co.*)

readings. With the landing-gear handle in the "down" position, both gauges should read the same. If they differ, use the higher reading, for they become weak in spring tension with continued use.

Four-way Valve for Internal Leaks.—Check the wing flap and landing-gear four-way valves for internal leaks by obtaining

20 in.-lb. drag on the plug. This is done by attaching the special 4-in. arm on the plug and applying a 5-lb. pull at the hole in the end of the arm. This gives a 20 in.-lb. drag on the plug.

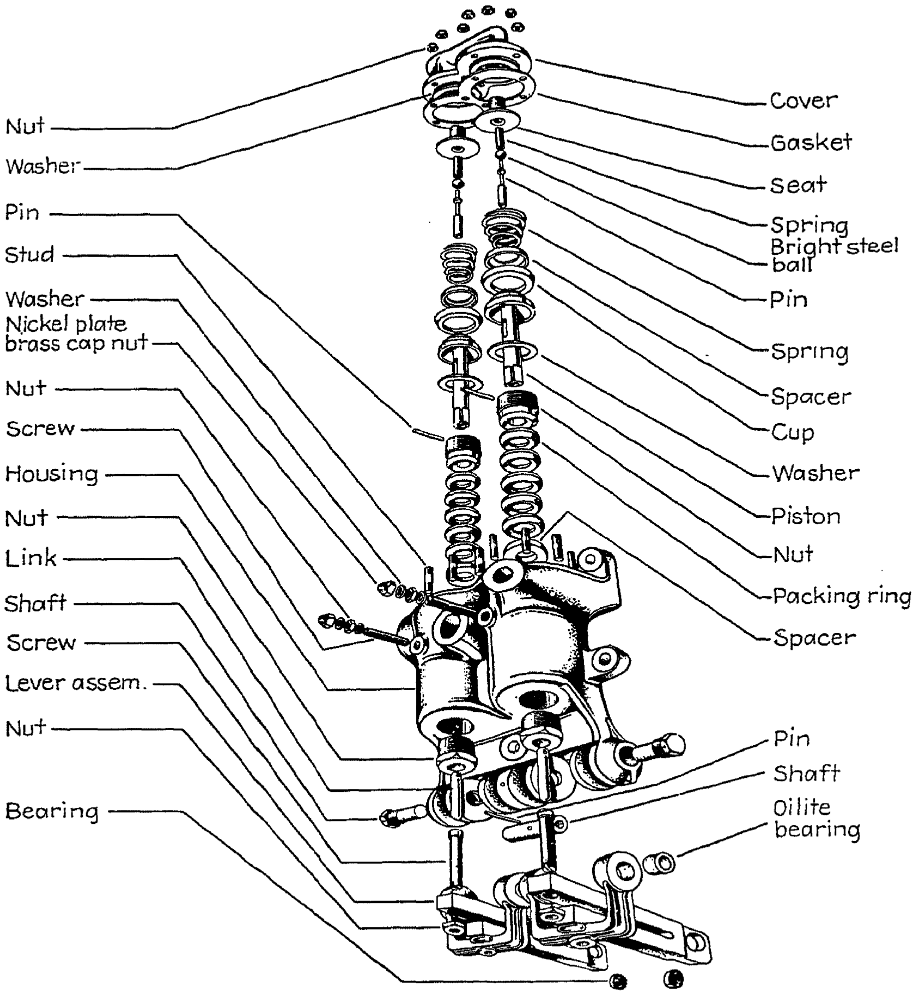


FIG. 226.—Valve assembly. Power-brake control. (*Courtesy of Douglas Aircraft Co.*)

Drop in Wing Flap.—If, while the plane is parked on the ground, the wing flap drops from the "up" position over a period of time, the flap selector valve is leaking internally. Tighten the plug to 20 in.-lb. drag as described above. If this does not correct the trouble, change the selector valve. If this is unsuc-

cessful, change the flap-operating cylinder, for the packing may be leaking internally (Fig. 225).

Brake Power Valve for Leak at Pressure Inlet.—To check for leaks at the brake-power-valve inlet-pressure check balls, place the brake pedals in the "full-down" position with approximately 600 p.s.i. on the hydraulic system. If the drop in pressure stops while the brake pedals are in the "down" position, then the

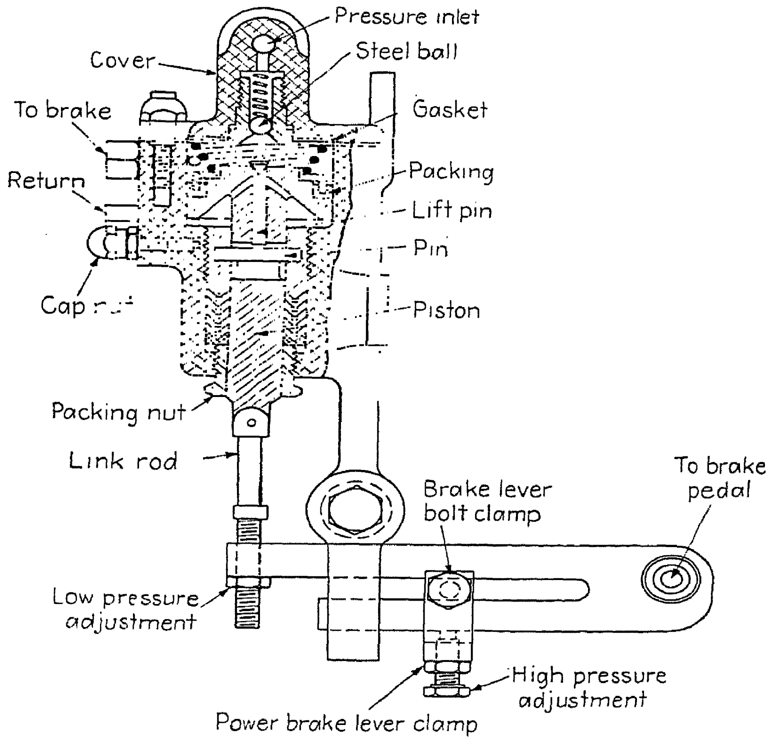


FIG. 227.—Brake control valve for a Douglas DC-3.

check balls are leaking, and the brake power valve must be replaced. Be sure to hold the brake pedal in the full-down position during this check (Figs. 226 and 227).

Engine-cowl-flap Cylinder and Valve.—If the ship is equipped with engine cowl flaps, operate each control valve separately, allowing the flaps to remain in the "open," "trail," and "closed" positions for a short while. If, when the flap valve is in the open or closed position, the pressure continues to drop after the flap has ceased to travel, the flap cylinder is leaking internally and

must be changed. The valve cannot be checked for internal leaks in the ship but must be removed and checked on the bench (Figs. 228 and 229).

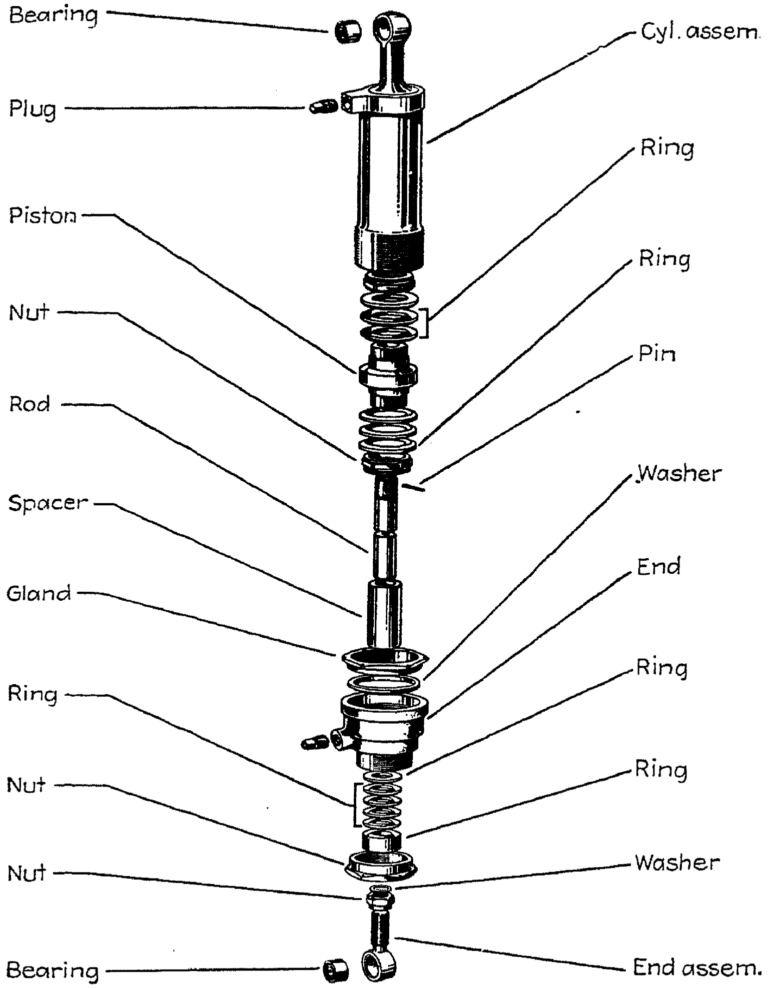


FIG. 228.—Cowl-flap operating strut. (*Courtesy of Douglas Aircraft Co.*)

If an external leak appears at the control valve during this process, change the valve, for the leak is probably a packing leak.

Check Valve between Hydraulic Manifold and Incoming Pressure.—To check the check valve between the hydraulic manifold and the incoming pressure from the engine-driven gear pump, remove the line between the T on top of the hydraulic-

pressure regulating valve and the check valve at the bottom of hydraulic-pressure regulator, and watch for fluid leaks at this check valve. With the pressure on the system, this valve should not leak; if it does, check or change the valve (Fig. 232).

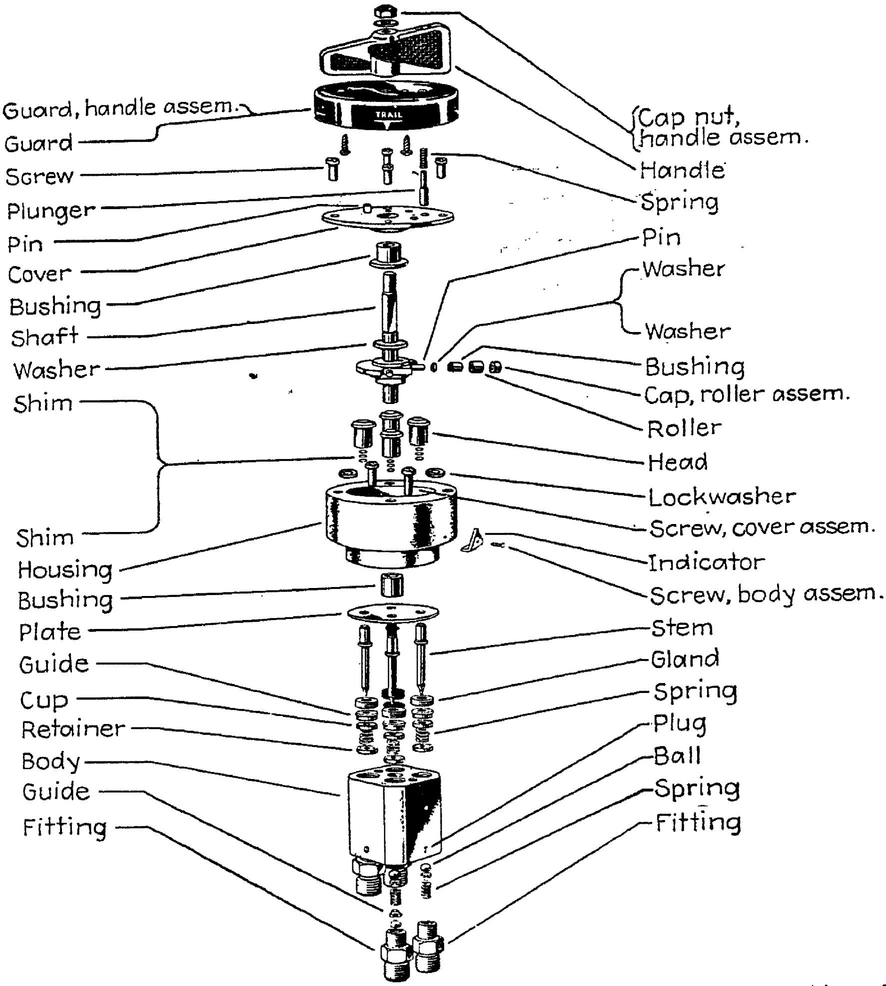


FIG. 229.—Valve assembly. Cowling flap. (*Courtesy of Douglas Aircraft Co.*)

1,000-lb. Relief Valve and Pressure Regulator.—These two must be removed as a unit. They can be checked on the hydraulic bench only. Therefore, if all tests fail to indicate the source of trouble, remove this unit and replace it (Figs. 219 and 220).

Ball Check Valves at Hydraulic Hand Pump.—If the system pressure still continues to drop after replacing the 1,000 p.s.i. relief valve and pressure regulating valve, replace the hydraulic hand pump. Both check valves that check fluid to and from

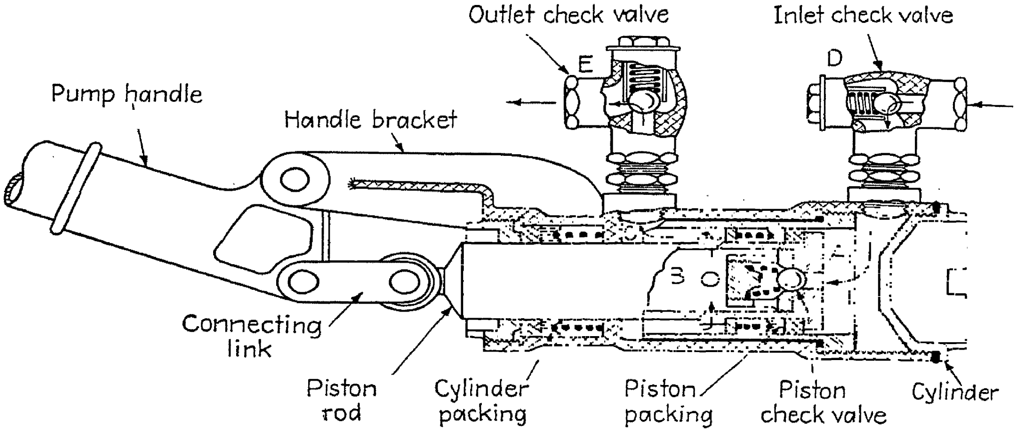


FIG. 230.—Schematic diagram of a hydraulic hand pump for a Douglas DC-3 hydraulic system.

the hand pump may be leaking at same time, though this is not probable. Therefore, make this check only as a last resort (Figs. 230 and 231).

Check Valve between Accumulator and High-pressure Manifold.—To check the check valve between the accumulator and

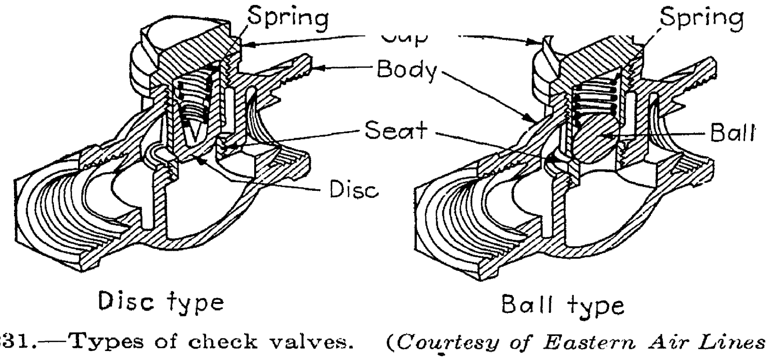


FIG. 231.—Types of check valves. (*Courtesy of Eastern Air Lines, Inc.*)

the high-pressure manifold, close the star valve on the front of the hydraulic panel and attempt to operate the hand pump. If the hand pump is deadlocked, the valve does not leak; if the pump handle can be moved up or down, the valve leaks and must

be replaced. If the pump can still be operated, replace the inlet check valve on the hand pump.

Brakes for Not Holding.—The following procedure should be used to check the brakes for not holding (Fig. 214).

1. Check the fluid pressure on each side of the wheel with the hydraulic gauge connected at the bleeder valve. The pressure should be 225 p.s.i. If the pressure is lower than this, then the brake power valve should be adjusted to bring the pressure at the brakes to 225 p.s.i.
2. Check for grease or oil on the brake lining or for external leaks in the brake expander tube.
3. Bleed the brakes of all air by
   a. Killing all pressure in the system.
   b. Operating the hand pump slowly, not to exceed 10 lb. on the main system, until approximately 1 qt. of fluid has flowed from each brake with the brake pedals in the "full-down" position or until all air bubbles vanish.
4. Check the clearance between the brake lining and the drum through the inspection hole in the brake cover. This clearance should be maximum 0.035 and minimum 0.015. If the clearance is over 0.035, replace the brakes. If under 0.015, replace the brakes.

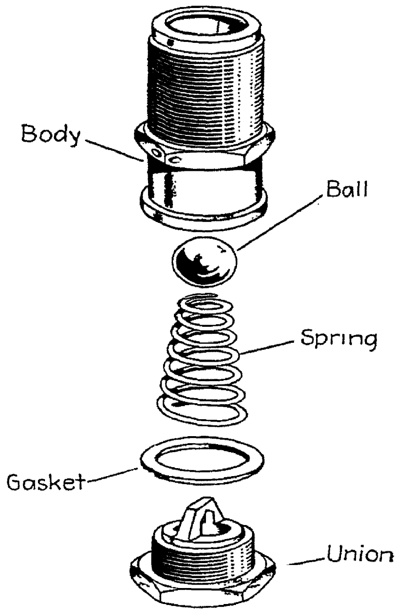


Fig. 232.—Valve assembly. Hydraulic-pump suction-line disconnect. (*Courtesy of Douglas Aircraft Co.*)

Hydraulic Supply Tank.—To fill the hydraulic supply tank, kill all pressure in the hydraulic system, and fill the tank according to the instructions on the sight gauge (Fig. 218).

Landing-gear Oleo or Tail Oleo.—Deflate the landing-gear oleo by *removing the inner valve core. Do not remove the cap until all air pressure has been released.* Tighten the packing nut, and release slightly. Collapse the oleo fully. Then fill the oleo with fluid to the filler-plug level; install a new gasket on the filler plug and a new valve core; and inflate with booster air pump until the proper dimensions are reached (see plate on oleo for proper height) (Fig. 215).

If the tail-wheel oleo is a Cleveland type and shows external leaks, replace the strut. If the tail-wheel oleo is a Bendix type, adjust as for the landing-gear oleo.

B. While Ship Is in Flight or on Jacks

Spherical-tank Diaphragm Leak.—If an excessive drop in pressure is noted in raising or lowering the landing-gear flaps or in applying the brakes, the spherical tank is underinflated or the diaphragm is leaking. Check the inner valve core, and replace if necessary (Dill type). When replacing this valve, inspect the interior of the tank for the presence of hydraulic fluid. If the diaphragm leaks internally, fluid will come from the inner valve recess. With the booster air pump, pump up the air pressure to 250 p.s.i. No pressure should be indicated on the main hydraulic-pressure gauge during this operation. Two hours later, check the air pressure as described on page 244. If the pressure has not remained the same, check the clamp bolts with soap water for external air leaks. If the tank leaks, replace it (Fig. 221).

Flap Relief Valve Frozen.—If the wing flap locks in the "down" position when the flap selector-valve handle is placed in the "up" position, the down flap relief valve is probably frozen in that position. Replace the valve to remedy the trouble (Figs. 222 and 223).

Loss of Hydraulic Fluid from Supply Tank during Flight.—If fluid loss is noted during flight or running up the engines, clean or replace the screen at the bottom of the hydraulic supply tank. If the trouble continues, change the hydraulic engine-driven gear pumps, for they may be pumping air with the hydraulic fluid, which causes the fluid to foam and to overflow. The first operation, however, usually corrects the trouble.

Leaking Packing in Landing-gear Struts.—If, during flight, a loss in pressure is noticed with the landing-gear selector valve handle in the "up" or "down" position, the retracting-strut packings are leaking. Replace the retracting strut.

Cowl-flap Restricted Fitting.—If the engine cowl flaps lock in either the "open" or the "closed" position, clean the restriction in the valves located at the inboard side of each nacelle.

Air in Hydraulic Struts.—After installing landing-gear or flap retracting struts, operate them several times under full hydraulic-system pressure to remove all air that may be trapped in the strut. The fluid, under full pressure, absorbs the air and returns it to the hydraulic supply tank.

Singing Notes in Hydraulic Panel during Flight.—A singing noise in the hydraulic panel can usually be traced to two sources.

1. If this trouble is in the regulating valve, the valve will have to be replaced.
2. If it is in the return valve of the hydraulic supply tank, change this valve.

If the pilot reports that the pressure regulating valve cuts out or in 50 p.s.i. above or below normal pressure (cutout 800 p.s.i., cutin 600 p.s.i.), check the pressure gauges. If both gauges read the same, replace the hydraulic-pressure-regulating-valve unit. This will overcome the trouble.

TUBING, TUBE CONNECTORS, AND FLEXIBLE HOSE[1]

The various units of a hydraulic system are connected with some form of tubing and/or flexible hose. Aluminum, chrome-moly steel, and copper are the materials most commonly used in aircraft tubing. These tubes are available in a wide range of diameters and wall thicknesses.

Tubes are joined by means of tube connectors, usually of the same material. The Parker Appliance Company is one of the largest manufacturers of these products.

Tubing

Some of the factors governing the selection of tubing are corrosion, temperature, weight, mechanical strains, abuse, and pressures.

Copper tubing and brass fittings are sufficiently noncorrosive to be suitable for ordinary service in water and air and for engine fuels, oil, and other chemically inactive fluids. Aluminum-alloy tubes and fittings are suitable for the same services. Aluminum-alloy fittings are furnished anodic treated, but tubes are commonly furnished not anodized. If anodizing is desired, this should be done after the tube has been bent and flared. Carbon-steel tubes must be cadmium plated after bending and flaring, and carbon-steel fittings must be cadmium plated.

Aluminum-alloy tube is not recommended for high-temperature service. Copper tube and brass fittings are suitable on

[1] Much of the information on tubes has been furnished by the Parker Appliance Company.

steam lines of low temperature, but for temperatures above 500°F. steel or other high-strength materials should be used.

Because of its light weight, aluminum-alloy tubing and fittings are used wherever possible in aircraft.

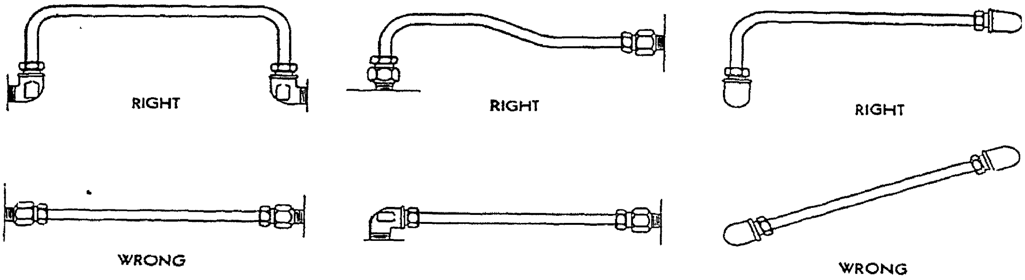


Fig. 233.—Right and wrong way to make tube installations. (*Courtesy of Parker Appliance Co.*)

Fittings are not pressure rated but are designed to withstand the bursting pressure that the tube of maximum wall thickness to be used will withstand, assuming that the tube and fittings are of similar materials. For general high-pressure installations, steel tube and fittings are recommended rather than heavy-wall copper tube and heavy brass fittings.

The selection of the proper tube to withstand mechanical strain and service abuse is a task for the engineering department.

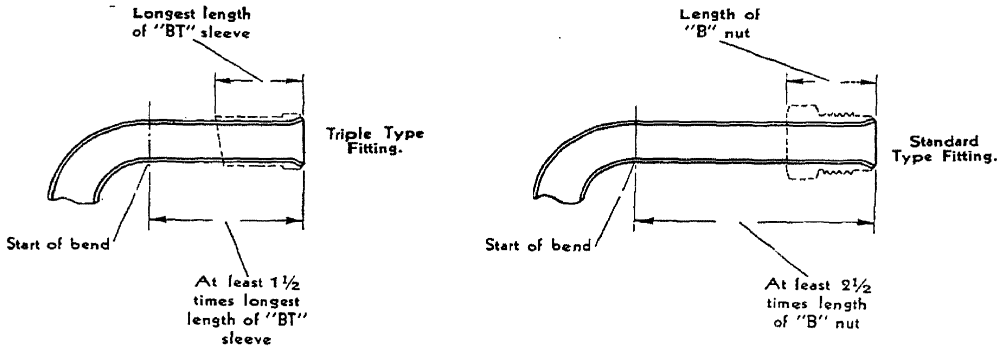


Fig. 234.—Correct length to allow when using "BT" sleeves or "B" nuts. (*Courtesy of Parker Appliance Co.*)

In general, the mechanic should allow ample material to take care of expansion of parts, vibration, etc. Also, he can greatly extend the service life of any installation if he will exercise care in disassembling and assembling.

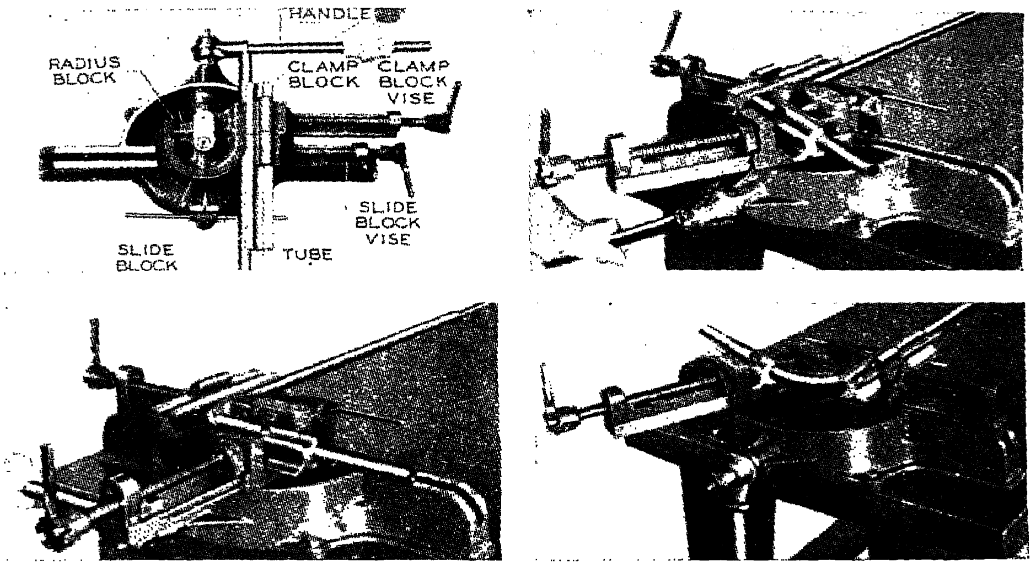


FIG. 235.—Parker production tube bender. (*Courtesy of Parker Appliance Co.*)

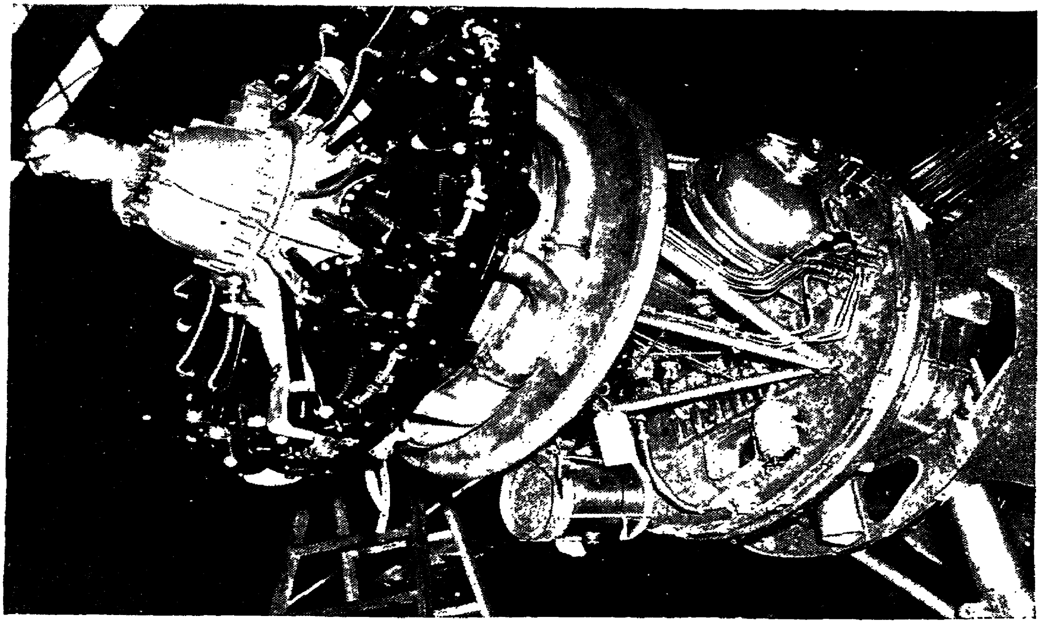
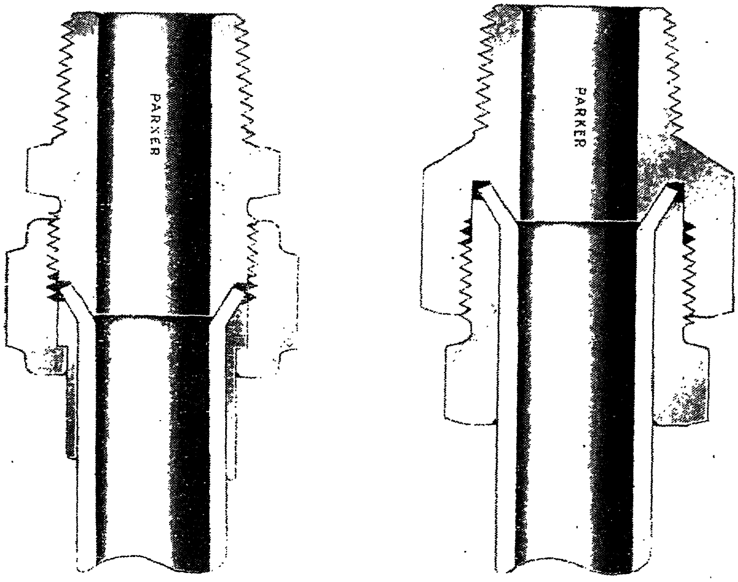


FIG. 236.—Here can be seen the tubing running down the inside of the leading edge of the wing, also the tubing from the fire wall to the engine as it passes under the oil tank of a Lockheed 14 passenger ship.

The selection of the size of tube is also an engineering problem. In making repairs, the mechanic should replace the tube with one of exactly the same material as that which he removed.

Arrangement of Lines.—Avoid laying out lines from point to point in a straight line, for this makes no allowance for expansion, contraction, and vibration and causes fabrication to be difficult. Figure 233 shows the right and wrong way to lay out a tube. If several tubes are to run parallel, make the system symmetrical.



(*a*) (*b*)

FIG. 237.—Two standard Parker tube fittings. (*a*) Triple tube coupling, (*b*) standard tube coupling. (*Courtesy of Parker Appliance Co.*)

This improves the appearance of the work and simplifies installation and service. Whenever possible, use fittings of the same type, but do not sacrifice smart design for economy.

To eliminate excessive use of fittings and to produce more efficient fluid flow, tubing is bent to obtain the desired direction. In making these bends, allow sufficient length for the fitting (Fig. 234). Also, do not bend the tube at too small a radius, or wall failure will result. To avoid this, standard radii of bend have been established for various tube diameters and wall thicknesses.

Small tubes may be bent by hand or with spring benders, but large-diameter tubes of small wall thickness should be bent on mechanical benders employing mandrels. This also makes a much cleaner job. Figure 235 shows one of these machines.

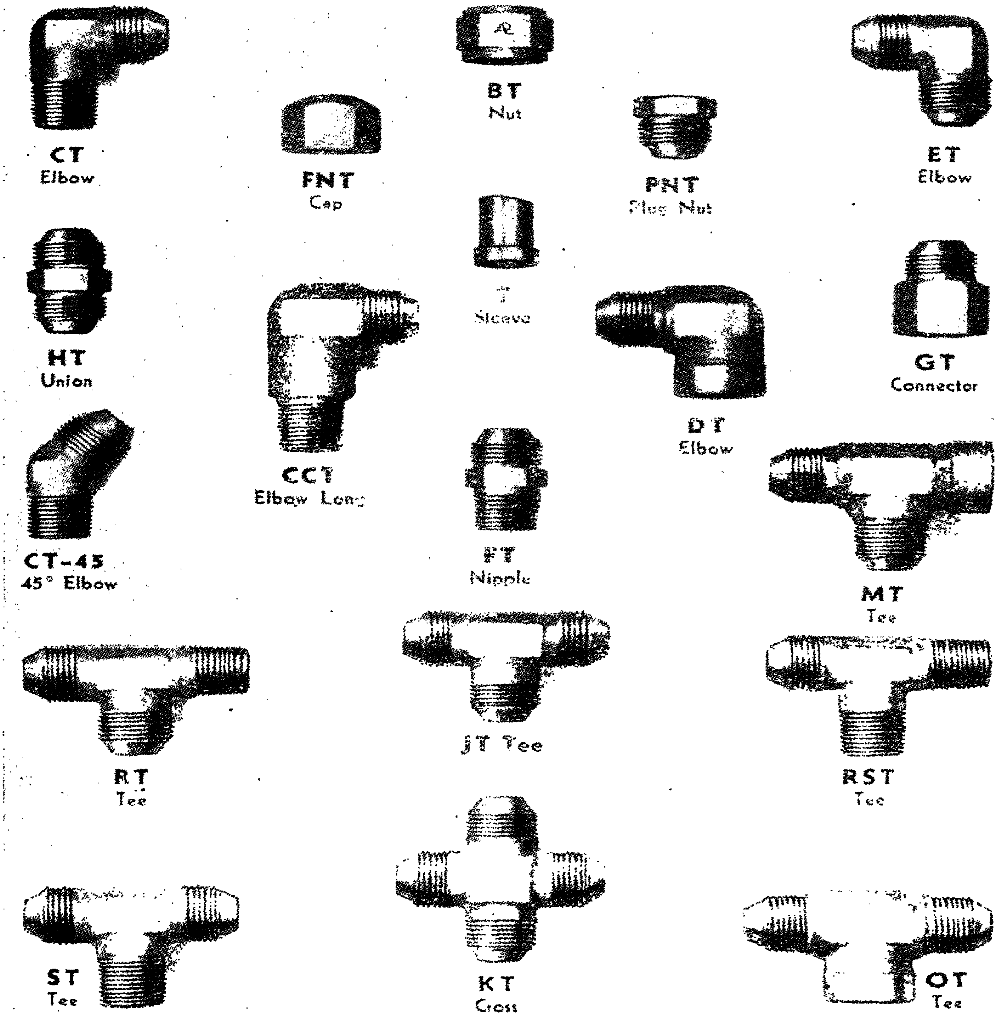


FIG. 238.—Triple-type tube couplings. (*Courtesy of Parker Appliance Co.*)

TUBE CONNECTORS

Many types of tube connector are available, but the flare type is the most widely used. Two types of flared tube connection

are shown in Fig. 237. The triple tube connector allows greater play for thread alignment and makes for easier installation. This type of connector is very useful in close quarters.

The importance of correct fabrication of tube connectors cannot be overemphasized. If the tube flare is made correctly, the connection will be stronger than the tube itself. However, if a poor flare is made, the connection will fail far below the

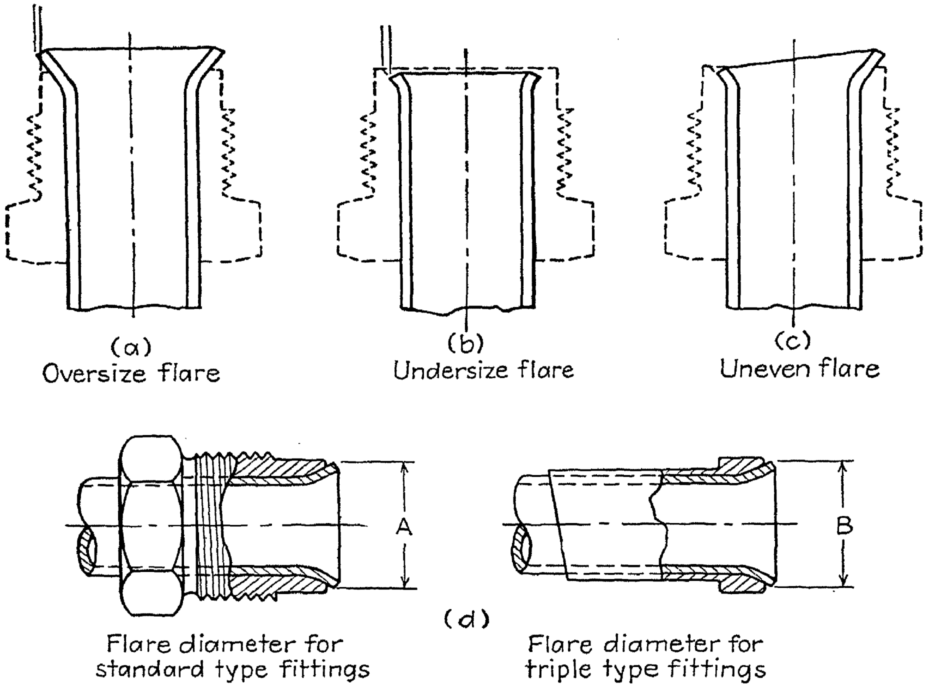


FIG. 239.—Three common errors in tube-flare fabrication (*a*), (*b*), and (*c*); and (*d*) correct tube flares. (*Courtesy of Parker Appliance Co.*)

bursting strength of the tube. Three mistakes most commonly made in the fabrication of tube flares are shown in Fig. 239*a*, *b*, and *c*. This figure also shows two correct flares.

If the flare is too short, the full clamping area is not utilized and the material will be squeezed thin. Such a connection may result in a split flare, leaks, or failure by pulling out (Fig. 239*b*).

If the flare is too long, it will stick and jam on the threads when assembled. It is likely to seat against the bottom of the coupling rather than on the tapered seat. Even strong wrench

pressure cannot be depended upon to give a good seat (Fig. 239*a*).

Uneven flares may be due either to eccentric cutting of the tube or to poor flaring technique. Such flares usually will not align with the seat properly, causing leaks. If the elongated side is too long it may hang on the threads. Too short a side will not give good clamping action (Fig. 239*c*).

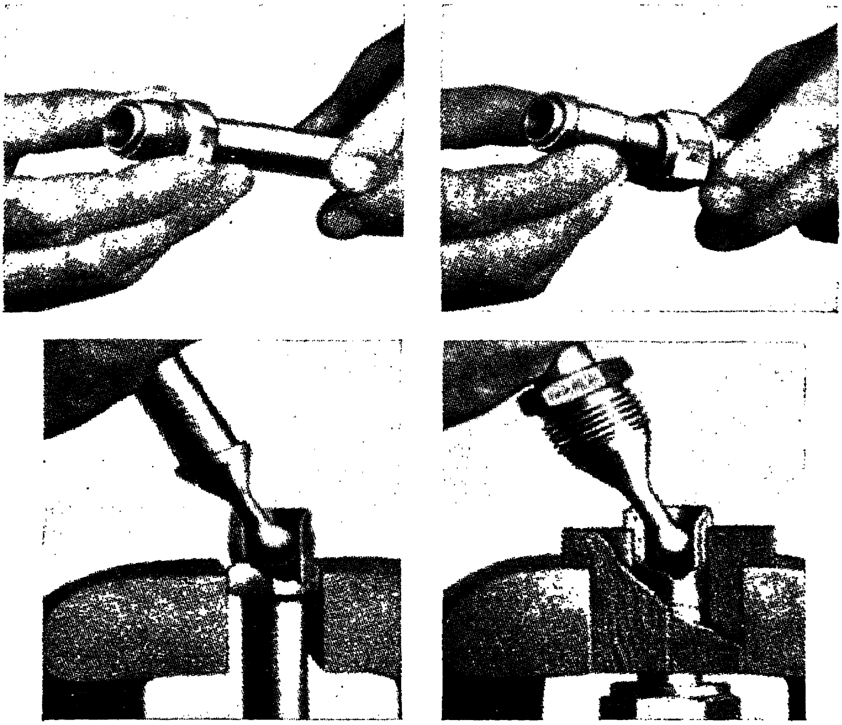


FIG. 240.—Ball-type flaring tool. (*Courtesy of Parker Appliance Co.*)

When the tube is cut for flaring, the end should be filed square, all bars and sharp corners removed, and the tube blown out with air pressure to remove all chips.

Two types of flaring tool are shown in Figs. 240 and 241.

Ball Type Tool.—Insert the tube in the nut, allowing enough material to form the flare, and clamp the nut in a vise. Insert the ball type tube to the shoulder, and rotate it in the tube, pressing outward and downward until the flare fits the nut. A slow circular wiping motion with firm even pressure to hold the

neck of the tool against the tube produces the best results (Fig. 240).

Hammer Type Tool.—Screw the tube nut and flaring tool together until only the last thread is showing. Insert the tube

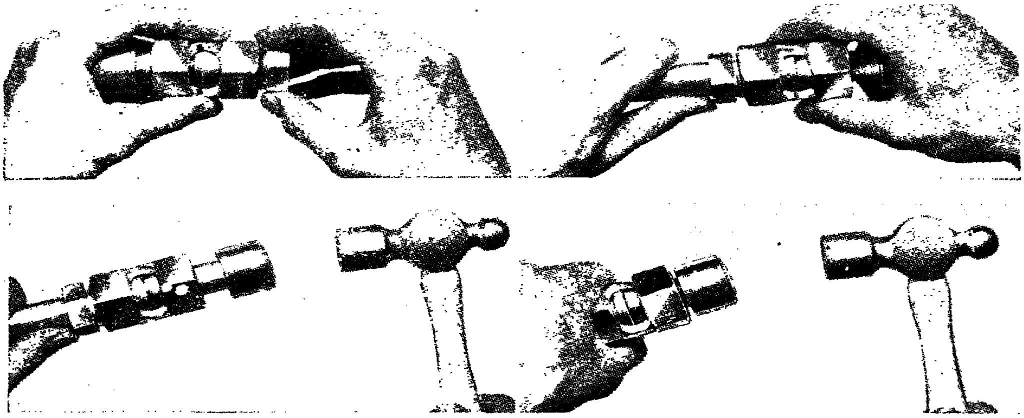


FIG. 241.—Hammer flaring tool. (*Courtesy of Parker Appliance Co.*)

as far as it will go. Hold the tube below the tool, and start the flare with a succession of moderate hammer blows. The first few blows should not be struck too hard, or the nut may become too tight on the tube (Fig. 241).

After the flare has been well started, screw the nut and flaring tool tightly together. Grasp the tool rather than the tube,

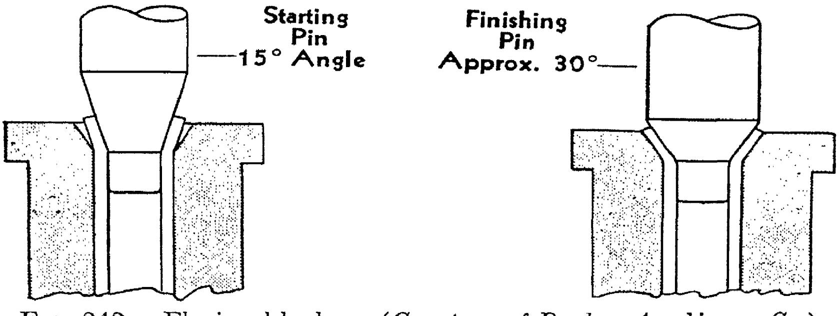


FIG. 242.—Flaring blocks. (*Courtesy of Parker Appliance Co.*)

and complete the flare. With the standard tool the progress of the flare may be observed through the cutaway section, or "window." The triple tube type of tool must be unscrewed for inspection of the progress of the flare.

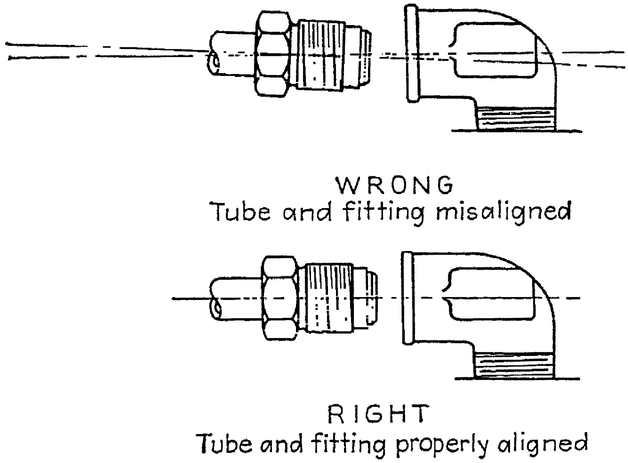


FIG. 243.—Alignment of tube and fitting. (*Courtesy of Parker Appliance Co.*)

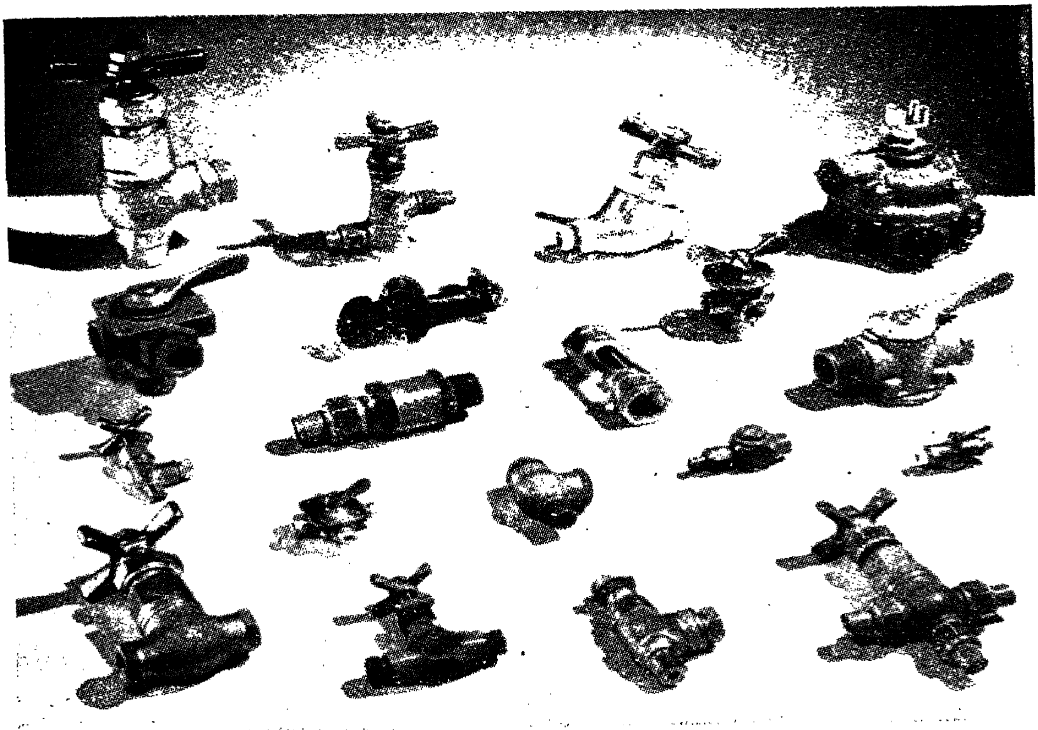


FIG. 244.—Typical variety of valves. (*Courtesy of Parker Appliance Co.*)

Flaring Blocks.—Heavy-wall tubes and steel tubes should be flared with flaring blocks (see Fig. 242). All steel-tube flares should be tinned well and reamed to the proper angle after fabrication. This will ensure a perfect seat upon assembly.

Before assembling tube connectors, Parker Threadlube should be used as a lubricant. Also, the fittings should be aligned to make certain that the threads will not seize and gall. Should this happen, the threads may be severely damaged (see Fig. 243).

Various other appliances are shown in Fig. 244.

Flexible Hose

Between stationary parts and moving parts, flexible hose is used to connect hydraulic units. The connection between the

Fig. 245.—Flexible hose. (*Courtesy of Parker Appliance Co.*)

engine pump and the fire wall and between the nacelle and the retracting strut are good examples. These hose are made up of varying layers of synthetic rubber, fabric, and wire braid.

In installing flexible hose care must be taken that the hose is free from twists. Under pressure, a twist will rotate the hose and loosen the connection, causing failure. Any part of the hose subjected to scuffing should be wrapped with cord or leather to protect it. A typical flexible hose is shown in Fig. 245.

CHAPTER VI

ELECTRICITY

MAGNETISM

Any *substance* that has the ability to attract iron or steel is called a *magnet*. The *ability* to attract is called *magnetism*. There are three kinds of magnet, as follows:

1. The *natural magnet* is oxide of iron (loadstone) mined in the magnetized condition.

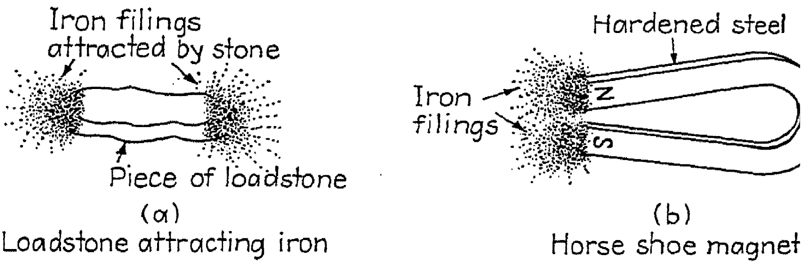


FIG. 246.

2. The *permanent magnet* is a magnet that holds its magnetism a long period of time, after being magnetized by magnetic induction.

3. The *temporary magnet, or electromagnet,* is a piece of soft iron, having a coil of insulated copper wire wound around it, through which is passed an electric current. The core is magnetized as long as the current flows through the coil but loses its magnetism immediately when the current stops.

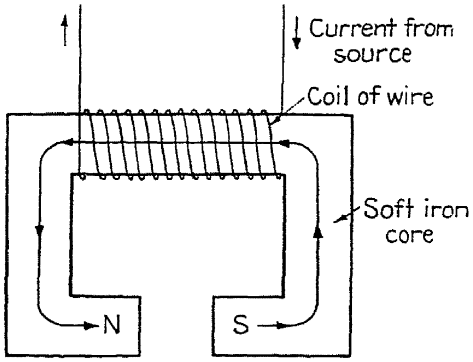


FIG. 247.—Electromagnet with soft iron core.

The two ends of the magnet have the greatest attraction for iron or steel and are called the *poles*. The pole that points or swings to the north when a magnet is free to turn is called the *north pole*. The other is called the *south pole* (Fig. 248).

The region around the magnet has peculiar properties that last only as long as the magnet is present. These peculiarities are (1) if any magnetic material is brought close to the poles of the magnet, a force will act on that material, tending to pull it toward the pole; (2) if two *like* poles of two different magnets are brought together, they will repulse each other; (3) if two

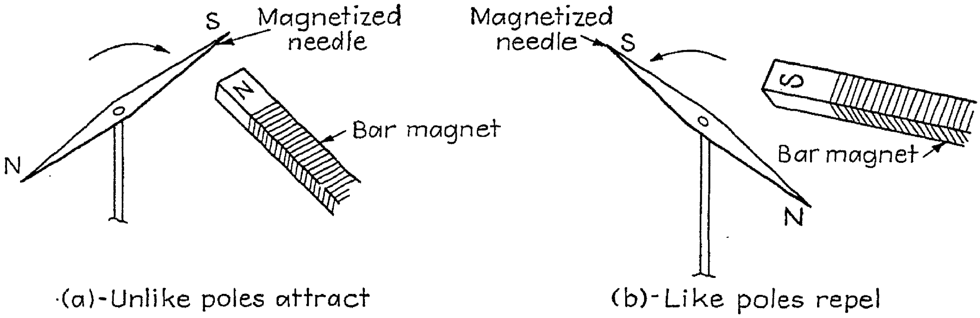


FIG. 248.—Magnetic attraction and repulsion.

unlike poles of two different magnets are brought together, they will attract each other (see Fig. 248).

The space around the poles of a magnet is called a *magnetic field.* If a piece of paper is placed over the poles of a common horseshoe magnet and iron filings are sprinkled over the paper, they will arrange themselves in definite curved lines, extending from pole to pole. These lines are shown in Fig. 249.

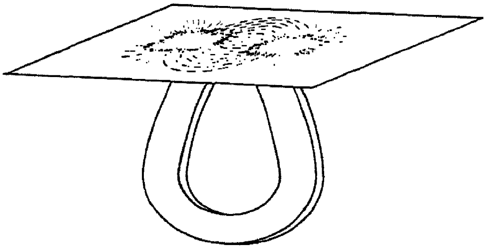


FIG. 249.—Magnetic lines of force.

The direction taken by the filings will indicate the direction of the *magnet field* (magnet lines of force).

The stronger the magnet, the larger number of lines of force. The total number of lines of force in the field is called *flux*, or the flux density equals the number of lines of force per unit of area.

$$B = \frac{\phi}{A} \qquad (67)$$

where B = flux density, lines per square inch.
ϕ = flux, or total lines of force

A = area, sq. in., of surface under consideration, taken at right angles to the lines of force

If two equal magnets are placed as in part *a*, Fig. 250, the field will be twice as great. If they are placed as in part *b*, the field will be canceled out.

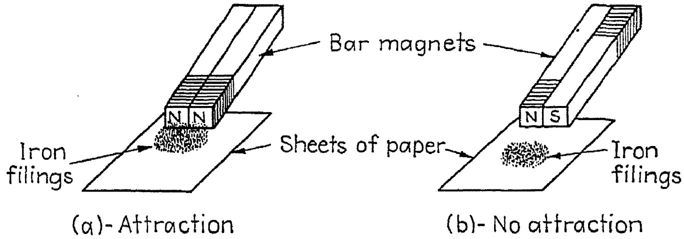


FIG. 250.—Illustrating the neutralizing effect of unlike poles.

If a loop of wire having its ends fastened to a very sensitive instrument (galvanometer) be moved through a magnetic field or a magnetic field be moved across this loop, the instrument will indicate a flow of current in the loop. If the wire is moved

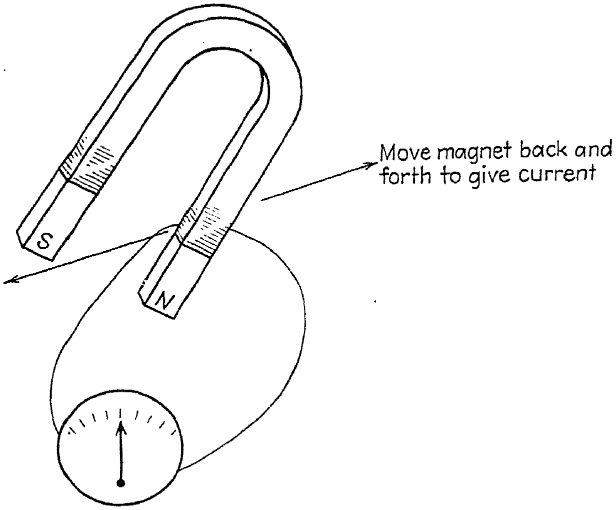


FIG. 251.—Induced current.

back across the field in the opposite direction, the current will also flow in the opposite direction. The current in the wire is called *induced current*, and the wire is called the *inductor* (see Fig. 251).

If the wire stops, even though it be in the strongest part of the magnetic field, there will be no flow of electric current indicated. This shows that, in order to obtain any current flow, either the magnetic field or the wire in it must be continuously moving.

CURRENT ELECTRICITY

The flow of electricity, which is called *electric current*, flows through the copper wire just as water flows through a pipe. Although electricity is not a liquid, it may be likened to water. In order to understand the flow of electric current, which cannot be seen, it must be compared with something that can be seen and understood. For this reason, the flow of water will be used to illustrate the flow of electric current. Figure 252 will be used for the analogy.

THE AMPERE

The ampere is the electric equivalent of a gallon (of water) per second flowing through a pipe; *i.e.*, 5 gal. of water per second

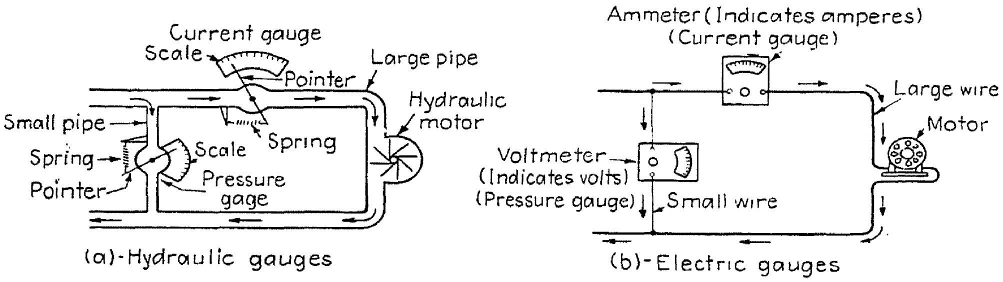


FIG. 252.—Hydraulic analogy illustrating amperes and volts.

through a pipe equals, electrically, 5 amp. per sec. through a wire, or 5 amp.

In order to measure the rate of flow of water through a pipe, it is necessary to place something in the pipe that will indicate this rate of flow. This can be done with the device shown in Fig. 252*a*, which could be a flowmeter. This device consists of a sheet of iron with a pointer attached and a scale by which to read it. This scale would be calibrated to read in gallons per second of water flowing through the pipe. The electrical equivalent is the *ammeter*, which is connected in the circuit much the same as the flowmeter in the water circuit. The true ammeter is always connected in series with the circuit (see Fig. 252*b*).

The Volt

The *volt* may well be called the electrical unit of pressure, as it refers to the pressure that causes electricity to flow. Voltage is also called *electromotive force* (e.m.f.). Voltage can never by itself accomplish anything electrical. That is, it cannot make a light burn, a motor run, or a soldering iron heat. Amperage in combination with voltage is always necessary to effect electrical results (see Fig. 252).

A meter, almost identical with the flowmeter in construction but connected with much smaller piping, so that the water lost in measuring the pressure is negligible, is connected between the pressure line and the return line. This measures the pressure differences between two pipes. In electrical terms this is called the *potential difference*. In Fig. 252*b*, it will be noted that the electrical circuit is almost identical with the water circuit in the principles of measurement.

Resistance

All bodies offer some resistance to the passage of an electric current through them, much as pipes offer opposition to the flow of water through them, owing to the friction between the running water and the sides of the pipe. No conducting bodies possess perfect conductivity. All bodies conduct differently, some offering more resistance to flow than others. When the resistance is small, the bodies are classed as *conductors*. When it is very high, they are classed as *insulators*. Electrical resistance is the opposition offered by any substance to the flow of an electrical current through it.

The *ohm* is the practical unit of electrical resistance.

Ohm's law is a rule that gives the relation between current, voltage, and resistance. It is one of the most useful laws of electricity, and is well worth the time spent in learning to use it correctly.

As there are just three forms of the law, it is best to learn the formulas as follows:

$$I = \frac{E}{R} \tag{68}$$

$$E = IR \tag{69}$$

$$R = \frac{E}{I} \tag{70}$$

where I = amperes
E = volts
R = ohms

The student should learn these formulas thoroughly, for they are absolutely necessary to an understanding of the subject.

Example 1: A voltage of 6 volts is used to force a current through a resistance of 3 ohms. What is the current?

Solution: From the first statement of Ohm's law,

$$I = \frac{E}{R} = \frac{6}{3} = 2 \text{ amp.}$$

Example 2: What voltage is required to force a current of 2 amp. through a resistance of 10 ohms?

Solution: The current I is 2 amp., and the resistance R is 10 ohms. To find the voltage E.

$$E = I \times R = 2 \text{ amp.} \times 10 \text{ ohms} = 20 \text{ volts}$$

Example 3: A voltage of 20 volts is required to force a current of 5 amp. through a coil. What is the resistance of the coil?

Solution: Voltage E = 20 volts. Current I = 5 amp.

$$R = \frac{E}{I} \quad \frac{20 \text{ volts}}{5 \text{ amp.}} = 4 \text{ ohms}$$

Power

Power is the rate of doing work and, electrically, is expressed in watts. The formulas for power are

$$P = W = EI \tag{71}$$
$$P = I^2R \tag{72}$$
$$P = \frac{E^2}{R} \tag{73}$$

where W = watts
P = power

Electric Circuits

Two types of circuits are used in electrical systems, series and parallel. They have different effects on current, voltage, and resistance.

Series Circuit.—If common dry cells are connected as shown in Fig. 253*a*, *i.e.*, positive to negative, etc., they are said to be *connected in series*. The total e.m.f. of such a circuit is the sum of the e.m.fs. of the individual cells. Thus, if the voltage of one cell is $1\frac{1}{2}$ volts, the total voltage drop for the circuit will be 6 volts.

If several resistances are connected in series, the total resistance of the circuit will be the sum of the individual resistances.

The only path for current to travel in such a circuit is through each device in the circuit. Therefore, the current through

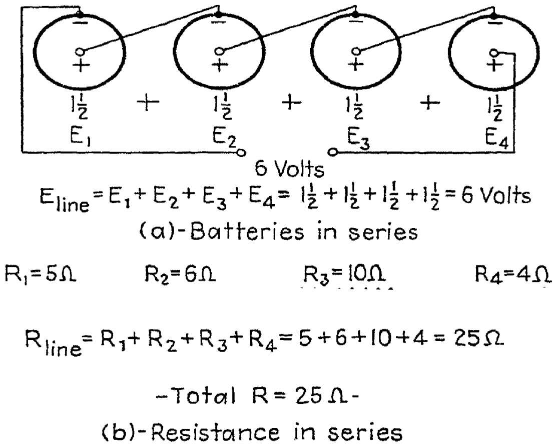


FIG. 253.—Series circuits.

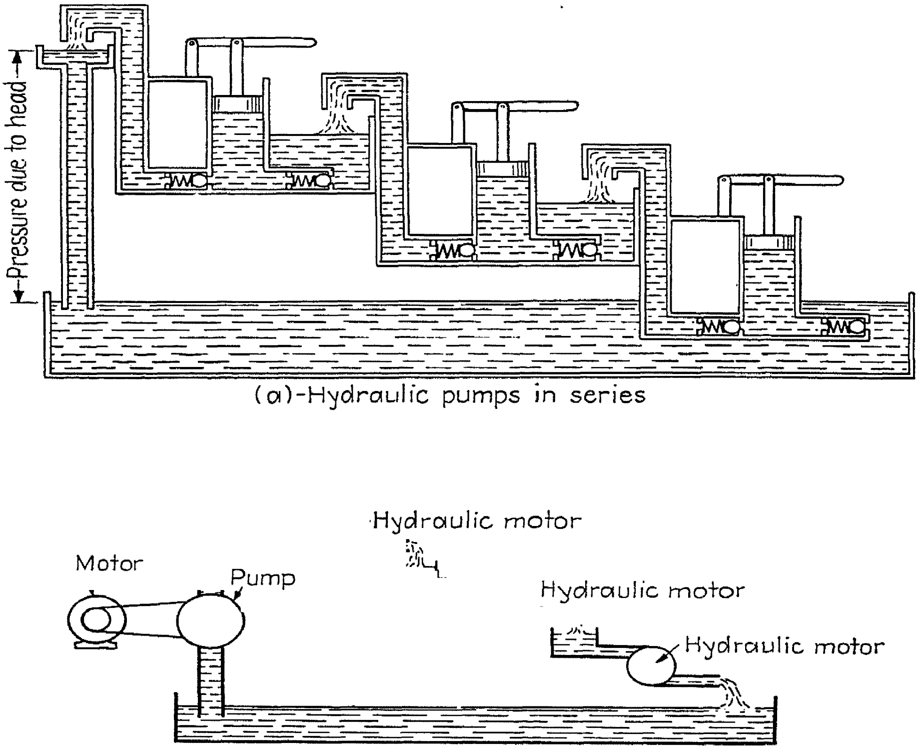
each unit in series is the same. This statement holds good regardless of how many units are connected in series. To measure the electric current flowing through any circuit, an ammeter is placed in the electric circuit; the meter will measure the current flowing through itself, this will be the current of the circuit.

If three hydraulic pumps are placed in series, the final pressure will be the sum of the individual heads, or pressures. Since the same volume of water passes through all pumps, the rate of flow remains the same (Fig. 254*a*). If the pumps are replaced with hydraulic motors, the pressure drop in the system will be the sum of the drops through each motor (Fig. 254*b*). Again, the volume of flow will be the same at all points.

The equations expressing the above facts are

$$R_{\text{line}} = R_1 + R_2 + R_3 + R_4 + \cdots + R_N \tag{74}$$
$$E_{\text{line}} = E_1 + E_2 + E_3 + E_4 + \cdots + E_N \tag{75}$$
$$I_1 = I_2 = I_3 = I_{\text{line}} \tag{76}$$

In Fig. 253*a* the voltage is equal to the combined voltage of all the cells, but the current is equal to that of one cell only. However, there is no current being generated in the batteries, nor is there any current flowing through the line unless a complete electrical circuit is made from one end of the batteries to the other. If little resistance is offered by the completed



(a)-Hydraulic pumps in series

(b)-Hydraulic motors in series

FIG. 254.

electrical circuit, a great amount of current will flow and the batteries will be exhausted in a short time. If much resistance is offered by the completed circuit, the current flow will be small.

When a 6-volt light is connected across the leads from these four cells (Fig. 255), it will light satisfactorily. It can be replaced with two 3-volt lamps, with the same results.

There are many objections to the use of series circuits. The chief of these is that, should one lamp in series burn out or be

turned off, all the rest will go out because the same current passes through all lamps.

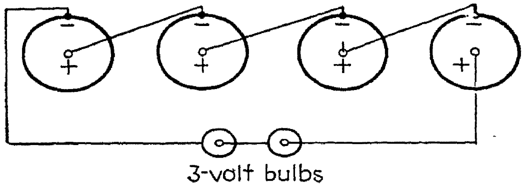


FIG. 255.—Bulbs in series.

Parallel Circuit.—If a group of cells are joined so that all the center terminals are connected to one line and all the outside terminals to the other line, as in Fig. 256, the cells are said to be *connected in parallel.* This type of circuit furnishes the voltage

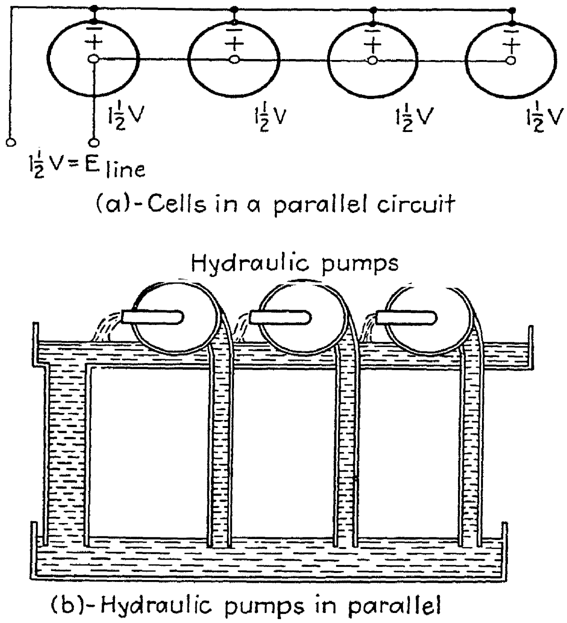


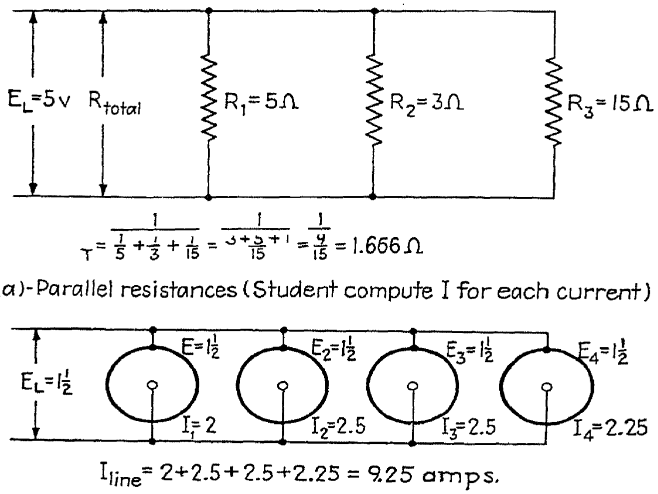
FIG. 256.—Parallel circuits.

of only one cell to the line but will furnish a current flow equal to sum of all the cell capacities. That is,

$$E_{\text{line}} = E_1 = E_2 = E_3 = E_N \tag{77}$$
$$I_{\text{line}} = I_1 + I_2 + I_3 + \cdots + I_N \tag{78}$$

$$R_{\text{total}} = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \qquad + \dfrac{1}{R_N}} \tag{79}$$

Because the line voltage is the same as the voltage of each cell, two cells of different voltage should never be placed in a parallel circuit. If this is done, a circuit will be set up between the two cells and part of the energy of the stronger cell will be consumed in forcing current through weaker cells. However, it is possible to connect on a parallel circuit cells of the same voltage but different ampere capacities.



(a)-Parallel resistances (Student compute I for each current)

(b)-Cells in parallel

FIG. 257.

The parallel circuit is widely used and is the type of circuit found in house installations. Lamps or lights in the same parallel circuit must have the same voltage rating, which, in turn, must be equal to the line voltage. The ordinary airplane lamp in common use is rated at 12 to 16 volts. This dual rating is due to the fact that, although the battery produces only 12 volts, the generator produces 16.

VOLTAGE DROP

Lights and other devices that are to be placed in a parallel circuit must be of a voltage at least that of the circuit. However, owing to the fact that line resistance is always present, a

loss in voltage must also be present in any circuit. This is commonly known as a *line drop*.

Since the resistance of the wires over which the current travels to reach the lamps is sufficient to cause a line drop, the voltage at the lamps is lower than the voltage at the battery. Thus, various points in a circuit differ slightly in voltage from the battery. At the end of the line the voltage is the lowest. In airplane wiring this voltage drop is usually so small that it is not considered at all.

The Wheatstone Bridge

The Wheatstone bridge is an arrangement of resistors and an indicating galvanometer, to check a resistor of unknown value by comparison with resistors of known values.

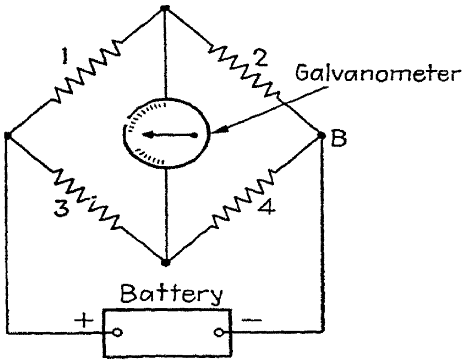


Fig. 258.—The Wheatstone bridge.

When a battery is connected across points *A* and *B* (Fig. 258), a current will flow from *A* to *B* through two paths, one through resistors 1 and 2 and the other through resistors 3 and 4.

Now, if all resistors in the circuit are of the same value, there will be no indication of a flow of current through the galvanometer. But should resistor 2 or 4 be variable and it is changed to a different value, there will be a flow indicated by the galvanometer, the direction depending upon whether the value of the resistor was raised or lowered.

This is the principle of several aircraft temperature indicators, the variable resistor being furnished by what is called the *resistance bulb*, which is installed at the point where the temperature is to be measured. It is made of such material that its resistance changes with the temperature and for every temperature change the bulb assumes a definite resistance (Fig. 259).

The Wheatstone bridge, of which the bulb forms one arm, will assume an unbalanced condition in a direction and proportion corresponding to the temperature to which the bulb is exposed.

The indicator acts as the galvanometer in the Wheatstone bridge and is calibrated in degrees of temperature. This type of indicator must be operated on some predetermined voltage,

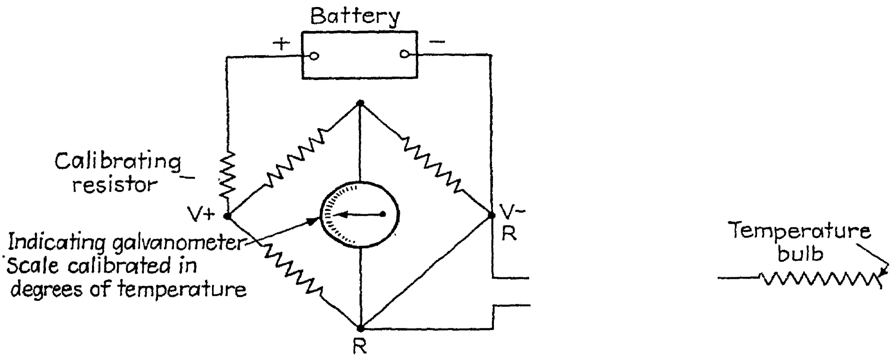


FIG. 259.—Temperature bulb instrument circuit (Wheatstone-bridge principle).

as the needle deflection will be out of proportion to the unbalanced condition of the bridge unless the voltage is held constant.

GENERATOR

It was stated previously that, if a loop of wire moves in a magnetic field, current will flow in the loop. A simple generator

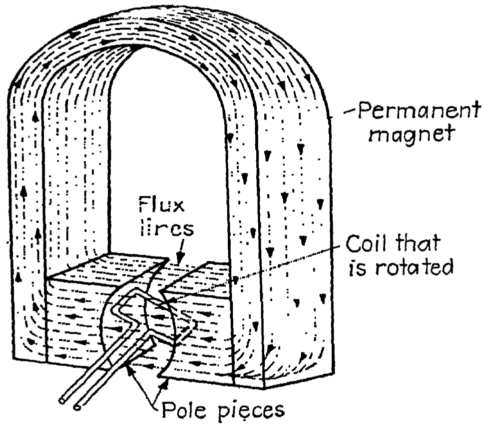


FIG. 260.—Elements of a magneto generator.

operates on this principle, and the loop of wire is called the *armature.* Permanent horseshoe magnets are used to provide the magnetic field for the armature, now a large number of

loops or wire. The inner ends of the pole pieces curve around the armature to give uniform magnetic field (Fig. 260). The current flow mentioned above is due to an induced e.m.f. in the coils. This e.m.f. increases with the number of loops, the speed at which the armature rotates, and the strength of the magnetic field. This is expressed by the following formula:

$$E \qquad \frac{N \times \phi}{100{,}000{,}000 \times t} = \text{volts} \tag{80}$$

where E = e.m.f., volts
ϕ = number of lines cut by loop
t = loop time to cut all lines, sec.
N = number of turns of wire

This formula will also hold good if a bar magnet is dropped through a coil of wire.

Example 1: Assume that there are 200,000,000 lines in a uniform field and that 1 sec. is required to move a bar at a uniform rate through them. Since cutting at the rate of 100,000,000 lines per second induces 1 volt, an e.m.f. of 2 volts will be generated during that second. If the resistance of the entire circuit, comprising bar and external circuit, is ½ ohm, the current will be:

$$I = \frac{E}{R} = \frac{2}{\frac{1}{2}} \qquad 4 \text{ amp.}$$

The power expenditure (the rate of doing work) will be

$$P = EI = 2 \times 4 = 8 \text{ watts}$$

Example 2: If a flux of 200,000 lines emanates from the north pole of a bar magnet, what will be the e.m.f. induced in the solenoid, while the magnet is being thrust to the bottom, if 1 sec. is required and the solenoid has 600 turns? It is assumed that all the flux of the magnet cuts each turn of the solenoid.

Solution: Substitute in formula (80).

$$E \qquad \frac{N \times \phi}{100{,}000{,}000 \times t} = \frac{600 \times 200{,}000}{100{,}000{,}000 \times 1} \qquad 1.2 \text{ volt}$$

It was discovered later that stronger magnetic fields could be produced by passing an electric current through a coil of insulated copper wire than could be produced by a permanent magnet. It was also discovered that if the coil of wire was placed around a soft iron bar the bar became magnetized and could be used as a magnet. When either the current or number of turns in the

coil was increased, the strength of the magnetic field increased. However, if the current ceased to flow in the coil, the soft iron bar immediately lost its magnetic force.

This principle is used in the manufacture of generators and motors. Soft iron bars in the shape of a horseshoe, with extended

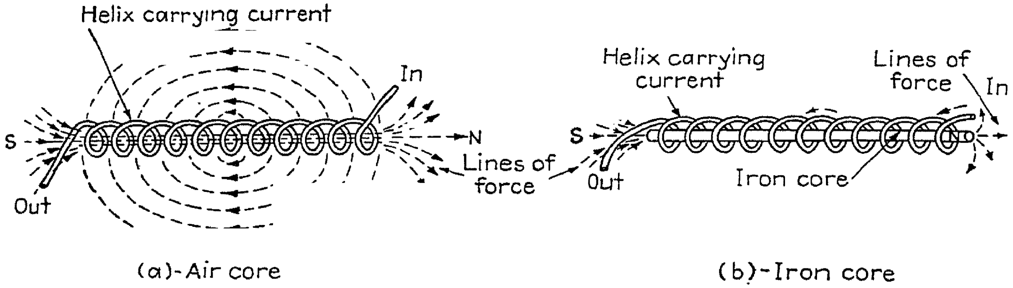


FIG. 261.—Illustrating effects of an iron core in a helix.

pole shoes and large coils of soft copper wire, replaced the permanent magnet. Current in the coils produces lines of magnetic force in the soft iron bars and a magnetic field in the gap, as in the permanent magnet (Fig. 263).

An electric generator may be thought of as an electric force pump that forces electricity to circulate in a circuit just as a

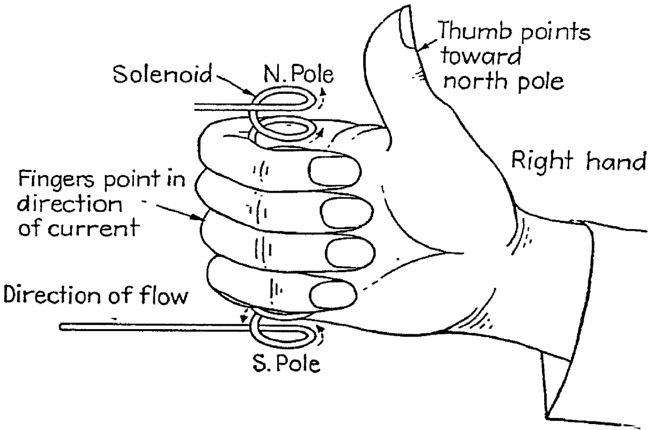


FIG. 262.—Right-hand rule for determining the polarity of a solenoid.

hydraulic force pump may force water to circulate in a hydraulic circuit (Fig. 264 and 265).

A simple form of direct-current (d.c.) generator uses a loop or coil of wire, as shown in Fig. 266, having two collector rings to

which the ends of the coil are attached. The brushes that carry the current to the external circuit are directly opposite each other on the commutator. When the coil or wire loop is in the position shown in Fig. 266, it is cutting the maximum number of magnetic lines of force of the field poles, and the maximum current is being induced in it in the direction shown. The current flows to the commutator through the positive brush to the external circuit and back to the commutator by way of the negative brush, forming a complete circuit. When the coil is rotated 90° beyond the position shown, it will no longer cut any magnetic lines of force and there will be no current induced in the coil in this position. Rotating the coil 90° beyond the neutral position will place it back in the magnetic field, where it will again cut the maximum number of magnetic lines of force and current will again be induced, this time in the reverse direction. As the coil rotates, the commutator segments to which the ends of

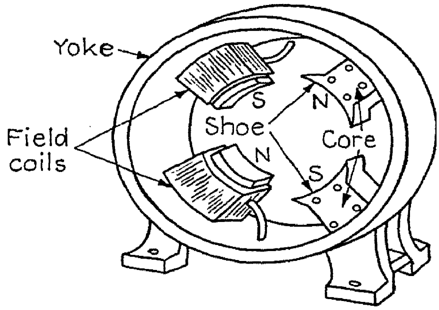


FIG. 263.—Field structure of a four-pole, direct-current generator.

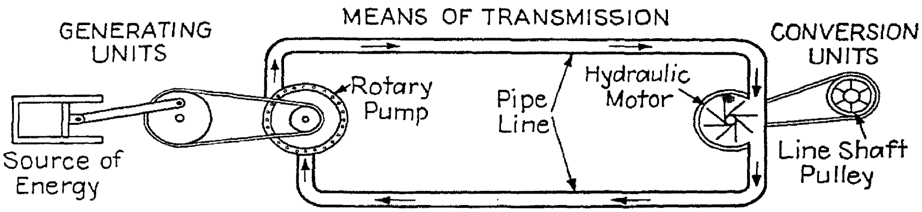


FIG. 264.—Transmitting energy by hydraulics.

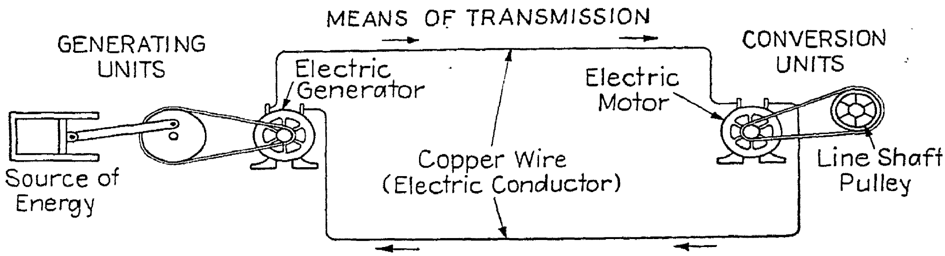


FIG. 265.—Transmitting energy with current electricity.

the coil are attached also rotate. Consequently, when current in the coil is reversed, the connections of the coil also reverse in relation to the external circuit; thus, the direction of the current flow in the external circuit will remain the same. Therefore, by reversing the connections of the armature coils in relation to the brushes and external circuit in this manner, alternating current (a.c.) may be converted into direct current. The positions of the commutator brushes of a d.c. generator have a definite relationship to each other and to the field poles, for the reversal of the connections of the coil must be synchronized with the reversal of e.m.f. in the coil.

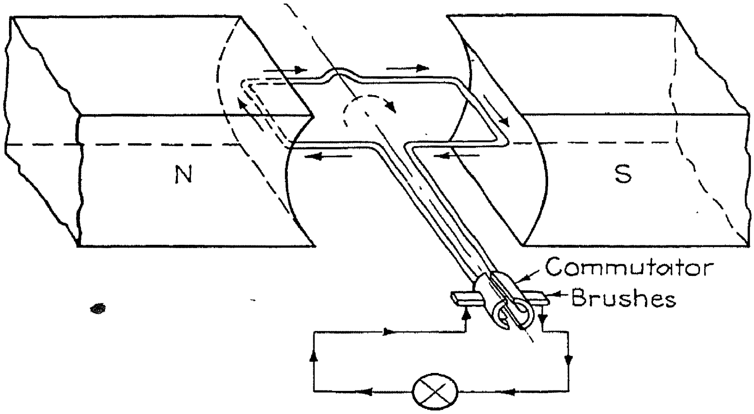


Fig. 266.—A simple diagram of a d.c. generator.

A generator with an armature coil consisting of a single turn of wire and two commutator segments, as shown in Fig. 266, produces a pulsating current. The voltage is constantly changing from zero to maximum value at each half turn of the armature. If additional turns of wire are added to the single-loop armature, a commutator with two segments being used, a higher voltage will be produced but the current fluctuations will remain the same. In order to reduce the number of current fluctuations per revolution of the armature, additional coils and commutator segments are required. It is impossible for a generator to produce voltage of constant value; however, by providing a large number of armature coils and commutator segments, voltage of nearly constant value can be produced.

Generators may be classified, according to the arrangement of the field windings, as *shunt wound* and *compound wound*.

Shunt-wound Generator.—The field circuit of winding of a shunt-wound generator is connected directly across or in parallel to the armature. The current in the shunt field is always directly proportional to the voltage produced in the armature and is not affected by current in the external circuit, unless there is a drop in pressure that acts across the terminals of the generator and field winding. The resistance of the shunt field winding is high, compared with that of the armature (Fig. 267).

When armature *A* (Fig. 267) begins to rotate, it cuts the lines of force of the residual magnetism in the N and S poles, inducing a slight voltage in the armature winding. This voltage causes current to flow from armature *A* to the positive generator brush,

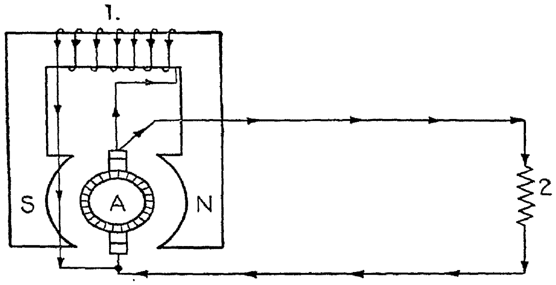
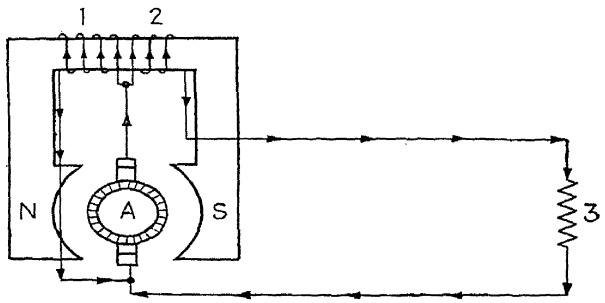


FIG. 267.—Circuit of a shunt-wound generator.

where the current is divided; part of it is conducted through field winding 1 and back to the negative brush, and part of it is conducted out on the armature circuit, through load circuit 2, back on the negative side of the armature circuit to the negative brush of the generator. As the amount of current that has been forced through the shunt field winding increases, the magnetic field strength is also increased. This increase in field strength results in a higher voltage to be induced in the armature winding. This finally reaches a point at which the induced voltage reaches its peak; here the field magnetism becomes constant and will remain so, if the speed of the armature is not altered.

Compound-wound Generator.—This construction has the ability of maintaining the voltage under a wide variation of current in the external circuit (Fig. 268). The generator has a series field winding 2 and a shunt winding 1. When current passes through them, the magnetization of the field poles is in

the same direction. The shunt field winding is connected as in the shunt-wound generator. The current in this coil is governed by its resistance and the generator voltage; consequently, as the resistance of the shunt winding remains practically constant, the current is always proportionate to the voltage. Series winding 2 is in series with the external circuit. When the circuit is open, the generator builds up in the same manner as the shunt generator, owing to the fact that no current is flowing through the series winding. The drop in voltage in the armature of a shunt generator is compensated for in the compound generator by the current in the series field coils. The increase in current



1. Shunt-wound coil 2. Series-wound coil 3. Line load

FIG. 268.—Circuit of a compound-wound generator.

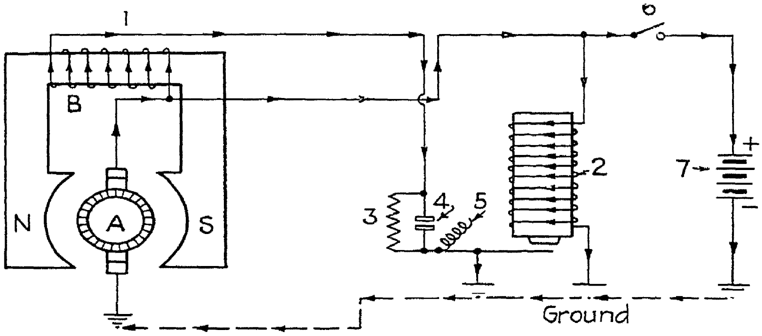
in the series coils increases the field strength, thus preventing a drop in voltage with an increase in amperes in the external circuit. This maintains a constant voltage at the generator terminals.

ELECTRIC UNITS

VOLTAGE REGULATOR

The voltage regulator is an electrical unit that controls the output of the generator as it charges the battery. It is adjusted to keep the generator voltage within certain limits and consists of a soft iron core, a shunt-wound coil of many turns, a stationary contact, a movable contact, and a high resistance. When the voltage of the generator has reached the predetermined value, the current strength through the shunt winding magnetizes the core to sufficient strength to overcome the spring tension and draws the points open (Fig. 269). If, when the contact point was open, there were no other path provided for the field current, total

field collapse would result and the generator voltage would drop to the residual value. To prevent this total field collapse, a resistance coil is connected across the points. When the points are opened, the field current will flow through this resistance. Owing to the higher resistance in the field circuit, a weakening of the field magnetism occurs. This results in a drop in the voltage produced in the armature of the generator. When the magnetic effect of the core holding the points open is less than the spring tension, the spring pulls them together, and the generator voltage rises again. This series of operations is repeated



1. Shunt wound generator
2. Coil (soft iron core)
3 High resistance
4. Contact points
5. Spring
6. Switch
7. Battery

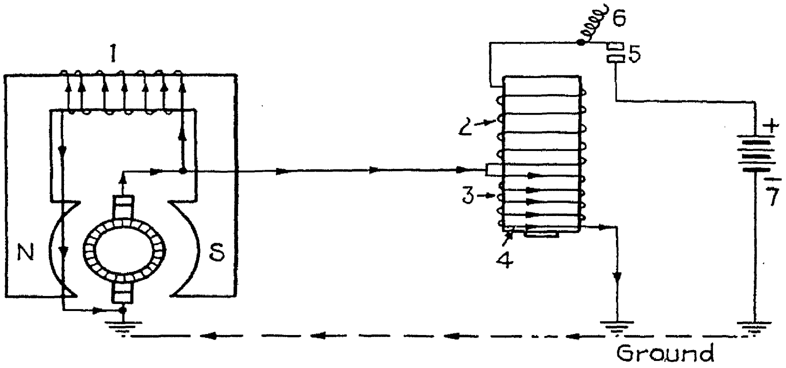
FIG. 269.—Circuits of a typical voltage-type regulator.

very rapidly and results in maintaining constant generator voltage.

Reverse Current Relay.—The reverse current relay is connected to the charging circuit between the generator and the battery. The points of this relay are normally open, so that whenever the voltage of the generator is less than that of the battery voltage the circuit between the generator and the battery will be open. This prevents the battery from wastefully discharging through the low resistance of the generator armature circuit. The reverse current relay also closes the circuit between the generator and the battery, thus permitting the battery to be charged whenever the voltage of the generator rises higher than that of the battery voltage (Fig. 270).

The reverse current relay consists of a double-wound coil and a set of breaker points. The double-wound coil has a soft iron

core, a high-resistance winding, and a low-resistance winding. The high-resistance winding, or shunt winding, of many turns of fine wire connected across, is in parallel with the armature circuit. On the outside of the shunt winding is the low-resistance, or series, winding, consisting of a few turns of heavy wire. Near the end of the core is a movable armature, which contains one of the contact points. The other point, fastened to a contact plate, is connected to one end of the series coil. The relay points normally are held open by a spring. The electrical principle of all reverse current relays is the same.



1. Shunt wound generator
2. Low resistance coil
3. High resistance coil
4. Soft iron core
5. Breaker points
6. Spring
7. Battery

FIG. 270.—Circuits of a typical cutout relay.

Figure 270 shows the circuits of the reverse current relay and the manner in which it is connected in the charging circuit. It will be noted from this figure that when the contact points are held open by a spring the connection between the battery and generator is incomplete. As the generator builds up voltage, it forces current through the shunt coil and back to the negative brush of the generator. No current at this time will be conducted through the series coil because the relay points are open. When the generator voltage has built up to a value higher than the battery voltage, the current flowing through the shunt coil will magnetize the soft iron core sufficiently to overcome the spring tension and close the contact points. The adjustment of the relay is accomplished by adjusting the spring tension. After the contact points are closed, the greater part of the generator

current will flow through the series coil, which is of lower resistance than the shunt winding. This completes the circuits. Whenever the generator voltage drops below the battery voltage, current starts to discharge from the battery, through the relay points, through series winding, and through shunt winding to ground. The current flowing through the shunt winding is in the same direction as when the generator was charging the battery, but the current flow through the series winding is in the opposite direction and is producing a bucking magnetic-field effect, resulting in the weakening of the magnetic strength of the soft iron core. When the magnetic strength of the core is less than spring tension, the spring will pull the points open, and the circuit between the generator and battery will be opened. This prevents further battery discharge through the generator.

Alternating Current

Most of the material so far presented deals with direct currents. Such a current always flows in a single direction around the

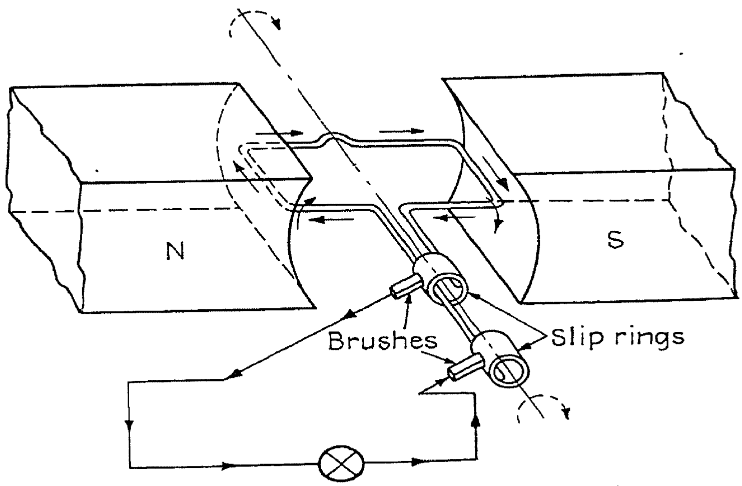


Fig. 271.—Simple diagram of a.c. generator.

electric circuit and is usually of a constant strength. An alternating current is one that changes its direction of flow at regular intervals of time. It will be noted (Fig. 271) that the simple a.c. generator is the same as the d.c. generator, except that it uses two continuous rings instead of the split type of commutator

used in d.c. machines. From previous study it is evident that this will produce an alternating current.

Alternating current is not generally used in aircraft, except for some instrument operation; but it is the most practical means of carrying currents over a long distance, as it can be carried at a high voltage. At its destination, it can be reduced by means of a transformer to a usable voltage. The fact that alternating current reverses its direction will cause the field continually to build up and collapse, thus supplying the varying flux necessary for magnetic induction.

Electric Tachometer

The a.c. tachometer magneto is a small low-voltage generator having four coils and a four-pole permanent magnet for a rotor.

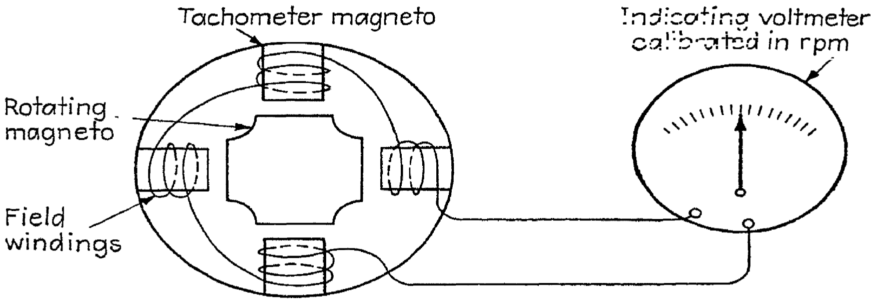


Fig. 272.—Alternating-current tachometer.

This rotor is driven at one-half engine speed by the outlet provided on the engine. The tachometer magneto develops voltage in direct proportion to the speed at which it is driven.

This voltage is measured by an a.c. voltmeter calibrated in r.p.m. This instrument is independent of the ship's electrical supply, and two leads carry the current from the tachometer magneto to the indicating voltmeter. Figure 272 shows the hookup.

Lead Storage Battery

The lead storage battery consists of a case made of composition or hard rubber and divided into compartments (six for a 12-volt battery) for holding the cells.

The plates, separators, connecting straps, terminals, and electrolyte make up the individual cells. The positive plate is a

lead skeleton into which has been formed or pressed lead peroxide, represented by the chemical symbol PBO_2. The negative plate is a lead skeleton onto which has been formed pure sponge lead.

The separators are a porous material made of rubber, wood, fiber, glass, composition, or a combination of two or more of these. The separators prevent the plates from "shorting" together and yet allow current and electrolyte to pass through them. They also serve as keepers to prevent the active material from falling off when the battery is subjected to vibration or heat or is required to furnish a heavy load.

The electrolyte is diluted sulphuric acid, the specific gravity depending on the purpose for which the battery was built.

Chemical Reaction Equations.

$$\underset{-\text{ plate}}{PB} + \underset{+\text{ plate}}{PBO_2} + \underset{\text{electrolyte}}{2H_2SO_4} = \underset{\text{both } (+) \text{ and } (-) \text{ plates}}{2PBSO_4} + \underset{\text{electrolyte}}{2H_2O}$$

where PB = lead
PBO_2 = lead peroxide
H_2SO_4 = sulphuric acid
H_2O = water
H_2 = hydrogen
O_2 = oxygen
SO_4 = sulphate radical
$PBSO_4$ = lead sulphate

This is a reversible equation. The left-hand side of the equation represents the charged condition, and the right-hand side of the equation represents the discharged condition.

It must be understood that the electrolyte is not pure sulphuric acid as shown above but is diluted with water and in the discharged condition is not pure water but a weakened solution of sulphuric acid. More electrolyte is present in the battery than is needed for the chemical reaction.

During discharge, the solution of sulphuric acid (called the electrolyte) is broken down into $2H_2 + 2SO_4$. The positive plate gives off the O_2 and combines with one SO_4 to form $PBSO_4$, while the O_2 that was given off combines with the $2H_2$ to form $2H_2O$.

The negative plate combines with the other SO_4 to form $PBSO_4$. Thus, it is seen that, during discharge, both plates change to lead sulphate, while water is formed which mixes with the electrolyte

to weaken the solution. This is why the specific gravity of the battery acid is lowered as a battery is discharged.

When a battery is connected to a source of d.c. power for charging, the following reactions take place: The water in the electrolyte is broken up into $2H_2 + O_2$. The SO_4 is driven from both the positive and the negative plates and combines with the $2H_2$ to form sulphuric acid, $2H_2SO_4$, again. The O_2 again combines with the positive plate to form PBO_2 or lead peroxide, while the negative plate is left pure lead.

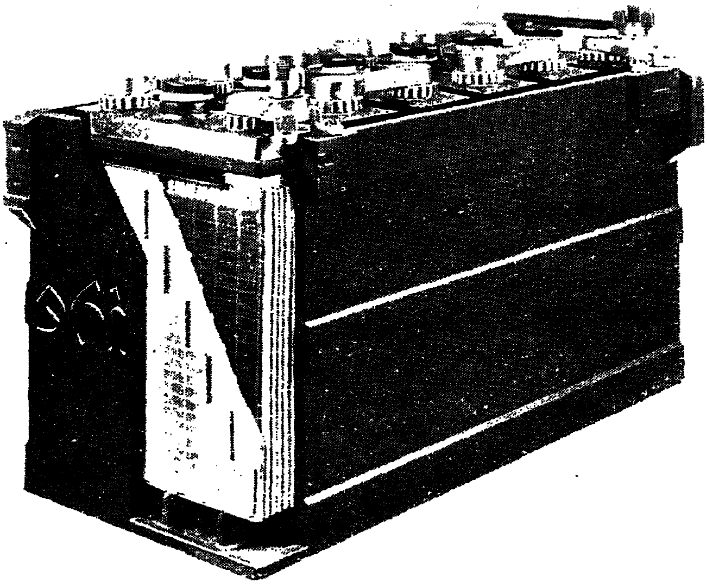


FIG. 273.—Cutaway of an aircraft battery. (*Courtesy of Electric Storage Battery Co.*)

The ampere-hour capacity of a battery is governed by the area and structure of the plates, type of separators, quantity and density of electrolyte, discharge rate, temperature, and age of the battery.

When a battery is fully charged cannot definitely be determined by the voltage and specific-gravity readings. If a battery is being charged at the normal rate and the specific gravity has not risen after three consecutive readings, taken 1 hr. apart, the battery is fully charged.

Gassing is the decomposition of the electrolyte, causing free oxygen, hydrogen, or both to be given off. Gassing occurs

when the charging rate exceeds that necessary for depositing the maximum rate of active material on the plates. During gassing, the specific gravity rises suddenly, owing to the higher concentrated solution being driven by the escaping gas from the cells in the plates and mixing with the weaker electrolyte.

Allowing a battery to remain in a discharged condition causes the lead sulphate, deposited on the plates during discharge, to become hard. Then, when the battery is charged at the normal rate, the lead sulphate is not easily dissolved; as a result, the battery overheats, and the active material is shed off and settles in the bottom of the battery case. Overcharging causes the active material to fall off the plates and also causes internal shorts between the plates.

The Thermocouple

If heat is applied to the junction of two dissimilar metals, a potential difference (e.m.f.) will be generated. The strength of the e.m.f. produced will depend upon the heat applied, the metals used, and the difference in temperature between the hot and cold junction, the hot junction being where the heat is applied and the cold junction being the connections at the indicating instrument.

The thermocouple indicating instrument is a simple millivoltmeter actuated by an electrical potential generated by temperature. Because one of the wires is a better conductor of electricity than the other, a differential of potential will be apparent at the meter, for heat applied to one end of the wires will cause a flow of electricity to the opposite, or cold, end. Although voltage generated by temperature is measurable only in one-millionth of a volt, it is nevertheless in direct proportion to temperature change. When a sensitive millivoltmeter capable of measuring this small electrical current is connected across the two conductors, it will indicate the slightest change in voltage. One of the conductors, the constantan, which offers the greater resistance to the flow of electricity, is connected to the negative terminal of the meter. The copper conductor, which offers the lesser resistance, goes to the positive terminal. The electric current generated by temperature will have a different value in each of the conductors, owing to their resistance to the flow of electricity. It is this difference in voltage which is indicated by the milli-

voltmeter. Instead, however, of the dial being graduated in millivolts, it is graduated in degrees.

The length and diameter of the couplers, or wires, are most important. Each instrument is calibrated to the wires provided with it by the manufacturers.

The wires should never be cut, and a meter that is calibrated, for example, for a 12-ft. coupler, should never be installed to a 6-ft. one.

Liquidometer Fuel Gauge

Liquidometer gauges are used on large transport planes that require an accurate means of indicating fuel quantity. They consist of four major elements: (1) the transmitting unit; (2) the voltage-compensator unit; (3) the stroke-adjustment unit; (4) the indicator unit (Fig. 274*a*).

Transmitting Unit.—This assembly is installed in the fuel or oil tank and is referred to as the *tank unit.* Normally, it is installed in the top of the tank. It consists of a variable-resistance unit, housed in a case and actuated by a *float,* which is attached to an arm, referred to as the *float arm* (Fig. 274*b*). The resistance element consists of a conventional wire-bound rheostat of correct resistance value, in ohms, to suit the installation. The variable resistance operates in series with the indicator and battery. The slipper arm *A* (Fig. 274*b*) moves about an axis in the center of the circular-shaped wire-bound rheostat *B* and is free to move from one extreme to the other, over the winding of the resistance. It is connected to the float and arm by suitable levers (see *C*, *D*, *E*, Fig. 274*b*). A diaphragm is provided between the rheostat and the float-actuating mechanism, to provide a positive seal, thus preventing fuel from leaking into the transmitter units. Operation is simple; the float-arm multiplying mechanism is attached to the tank side of the diaphragm and the rheostat unit to the top or outside of the diaphragm, and mechanical motion is transmitted through the movement of the diaphragm.

Voltage-compensator Unit.—This unit is of the Wheatstone-bridge principle and is used to maintain a constant voltage by compensating for battery-voltage fluctuation. Only one regulator is required, regardless of the number of tanks to be gauged, provided that one indicator is used.

Stroke-adjustment Unit.—This unit consists of two small variable resistors, one in each lead between the tank unit and the indicator. They are used to get the final adjustment of the "full" and "empty" position of the indicator.

Indicator Unit.—The indicating unit is a simple voltmeter with its scale calibrated in gallons of fuel. The deflection of this

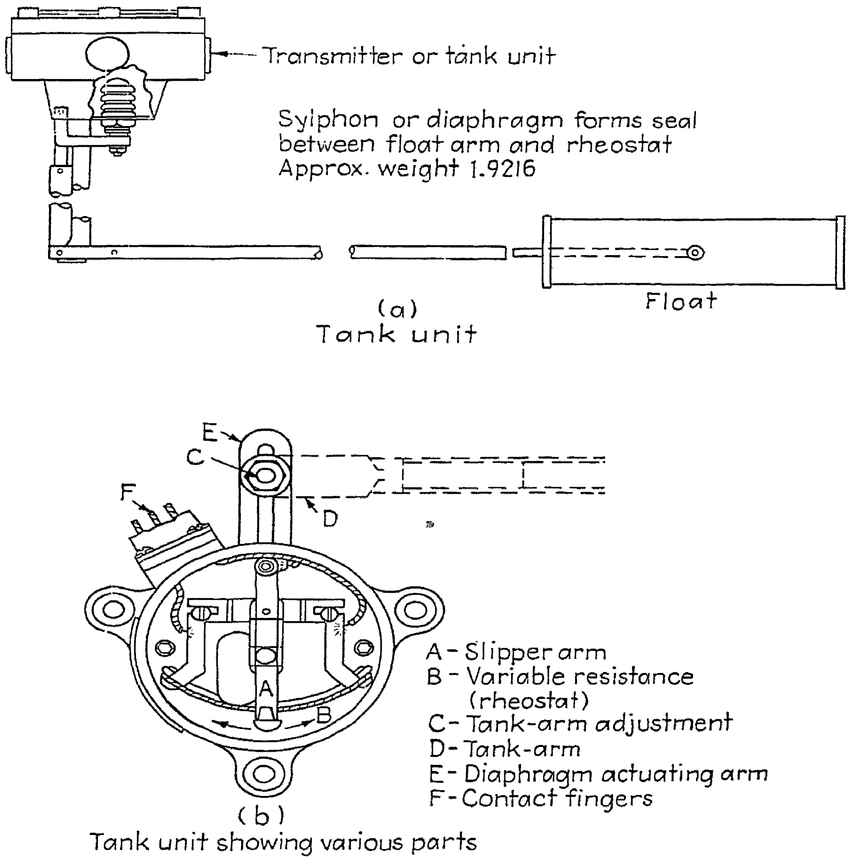


FIG. 274.—Tank-capacity gauge.

unit is caused by the change in resistance due to arm A moving on resistance shoe B (Fig. 275) when the tank is being filled with gas.

AUTOSYN

Basically, the Autosyn system employs the principles of self-synchronizing electric motors, *i.e.*, it has a stationary armature

called the *stator* and a rotating field called the *rotor*. If two of these motors are connected, as in Fig. 276, the single windings are the rotors and the Y connections are the stators. The inverter delivers 28 volts at 400 cycles to the windings of the rotor. One

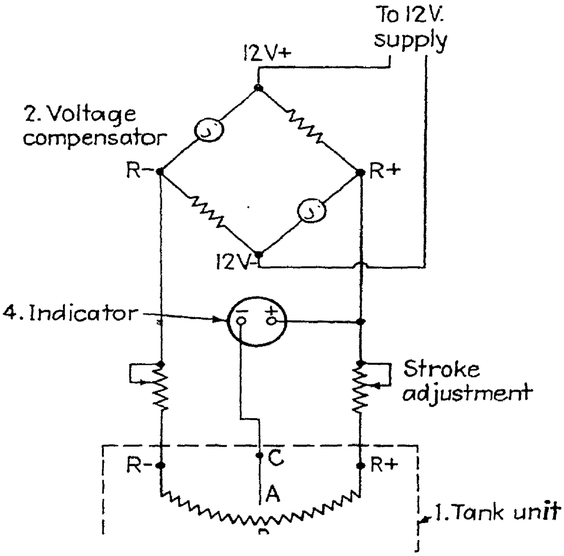


FIG. 275.—Gas-gauge diagram.

motor, the transmitter, is located at the engine or operating unit and the other motor, the indicator, is located in the cockpit.

Transmitter.—The rotor of the transmitter is operated by an outside force as a diaphragm or pressure tube. Unlike the synchronous motor, these rotors do not revolve but rotate

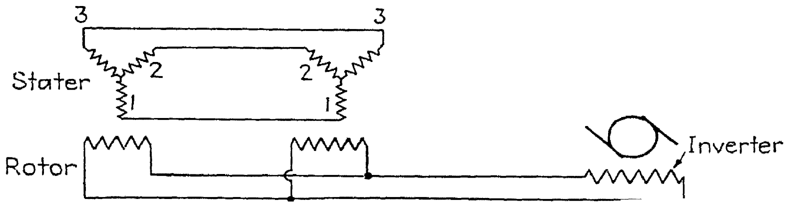


FIG. 276.—Autosyn wiring diagram.

through a small arc only. This arc is limited by the amount of travel of the outside-actuated mechanism. When the rotor is energized by the inverter and e.m.f. is induced in the three-phase winding of the stator, the amount of this voltage in each

winding depends on the position of the rotor. As the rotor is rotated by the outside force the induced voltage in the three-phase winding will change. This voltage is transmitted to the stator of the indicator.

Indicator.—The indicator resembles the transmitter except that the rotor is connected to a pointer that rotates over an appropriately calibrated dial. When the rotor winding of the transmitter is energized, the rotor winding of the indicator is

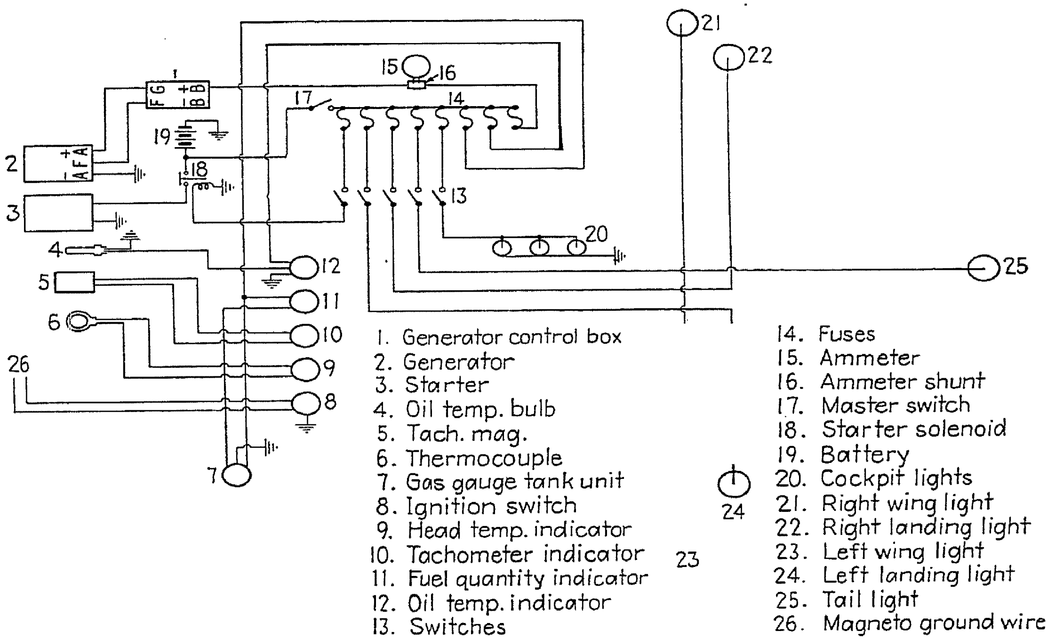


FIG. 277.—Typical electrical system for a single-engine airplane.

also energized. Therefore, when the induced voltage of the transmitter stator is transferred to the three-phase winding of the indicator stator, the same resultant flux is produced in the indicator, and the rotor of the indicator will assume the same position as the rotor of the transmitter. Any change in position of the transmitter rotor will also cause a corresponding change in position of the indicator rotor.

Fuses.—Lead containing a small percentage of tin is used in electric fuses for the protection of the copper conductor. It melts at a lower temperature than pure lead. A fuse is rated to be of so many amperes capacity. That is, it will carry a certain

quantity of current without melting or "blowing" and will melt on a slight increase in current above its capacity. The function of a fuse is to operate or blow before the temperature rise has an opportunity to overheat the conductor or damage equipment.

Fuses are for the protection of electrical apparatus and circuits. They should melt at a definite current value and not be influenced by long heating. They should maintain good contact with the circuit. They should be of a sufficient length and should be arranged so that surrounding objects will not be set on fire when they melt.

Electric System

Figure 277 shows a typical wiring diagram for a single-engine airplane.

CHAPTER VII

PROPELLER OPERATION AND MAINTENANCE

GENERAL

Propellers are divided into two classes, wooden and metal. Wooden propellers, laminated from birch, mahogany, and oak, were used altogether on the first airplanes. Today, however,

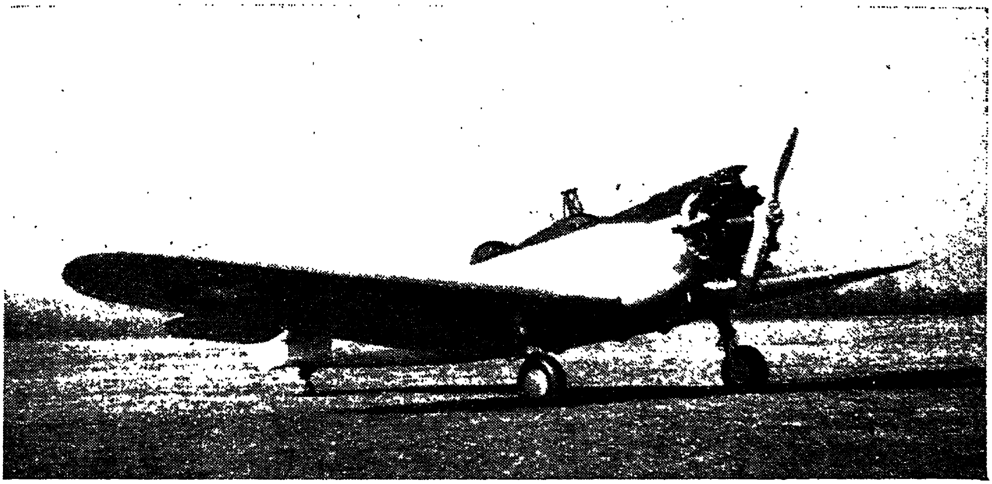


Fig. 278.—Aeronca trainer with a wooden propeller.

they are used only in the low-price field (Fig. 278). Metal propellers are made either of hard aluminum alloy or steel and may be fixed, adjustable, controllable, constant speed, or full feathering.

The early aluminum-alloy and the present wooden propellers are manufactured with a fixed pitch and can be manufactured to give maximum efficiency for only *one* of two conditions of flight, level flight and climb. This means that a propeller designed to give maximum horsepower for take-off and climb would not be efficient for level flight, and vice versa. The reason for this is as follows: If a plane is cruising in level flight with a level-flight propeller, the blade angle will be high. Consequently, the drag will be high, and the engine r.p.m. will be

at approximately 60 per cent rated power (see Chap. III and Fig. 114). If the ship is placed in an attitude of climb, the pitch angle will increase. This is equivalent to increasing the angle of attack of a wing. Therefore, the drag will increase. Since the engine is developing maximum horsepower for that throttle setting, this extra load will slow the engine down. If the ship is placed in a dive, the pitch angle will be less, the drag will be less, and the engine will speed up.

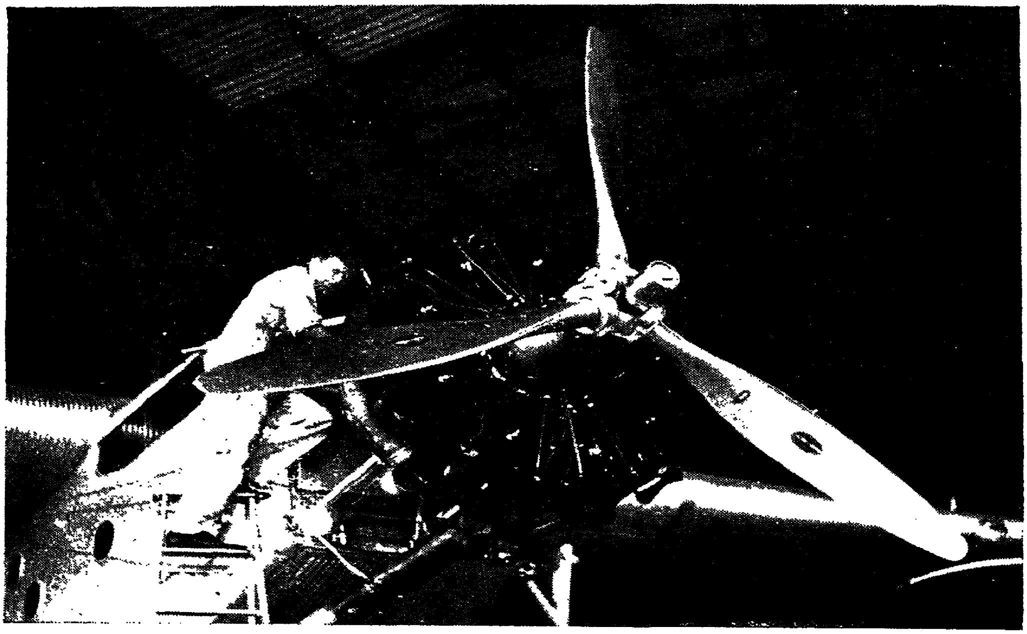


FIG. 279.—Two-position Hamilton Standard propeller.

The climb propeller has a low pitch angle (therefore a small angle of attack and low drag) to allow the engine to develop full horsepower by increasing the r.p.m. The level-flight propeller has a larger blade angle, giving greater efficiency at lower r.p.m. In order to obtain greater efficiency for both take-off and cruise, the two-position controllable propeller was developed. This gave maximum horsepower for take-off and good efficiency for cruise but did not give good efficiency for intermediate positions, as cruise climb and descent. This is the reason for the constant-speed propeller. The full-feathering hydromatic and electrical propellers permit the blades to be turned parallel to the air stream to prevent rotation and possible

further engine damage after engine failure. The full-feathered propeller also offers much less drag than a windmilling propeller, thus making possible safer single-engine operation.

Fixed and Adjustable

The fixed aluminum-alloy blades were manufactured from flat sheets of metal bent to the desired shape in manufacture. This gave a thinner yet stronger section that was more efficient than the wooden propeller. However, the cost limited its use. Also, as with the wooden propeller, once the blade angle was set, it could not be changed.

To enable the mechanic in the field to change the pitch to fit the occasion (climb or cruise) or the engine, adjustable propellers were manufactured. Their blades (forged aluminum alloy) had round root sections that were clamped between two hub halves. By loosening the hub clamp bolts the blades could be rotated to any desired angle. Once the engine was operating, however, the angle could not be changed.

HYDRAULICALLY OPERATED PROPELLERS

Two Position

The adjustable propeller was followed by a two-position controllable-pitch propeller. Some of these propellers are still in use in the medium-horsepower bracket. The high- and low-pitch settings of this propeller are controlled by means of a three-way valve operated from the cockpit. When the valve is placed in the low-pitch position, oil pressure from the engine operates a cylinder attached to the nose of the propeller shaft. As the cylinder moves forward, it rotates the blades, placing them in the low-pitch position. When the control valve is placed in the high-pitch position (cruise), the oil used to operate the cylinder drains back into the engine and the counterweights, attached to the blades and operated by centrifugal force, place the propeller in the high-pitch position. A two-position propeller is shown in Fig. 279.

Constant Speed

The constant-speed propeller permits the pilot to maintain a constant r.p.m. regardless of the attitude of the ship or the throttle setting. It is also possible for the pilot to obtain a wide

range of power. Such propellers may be electrically or hydraulically operated.

The Hamilton Standard propeller (forged aluminum alloys) operates on the same principle as the two-position propeller but includes an automatic governor and control. The oil pressure operates the propeller toward the low-pitch position against

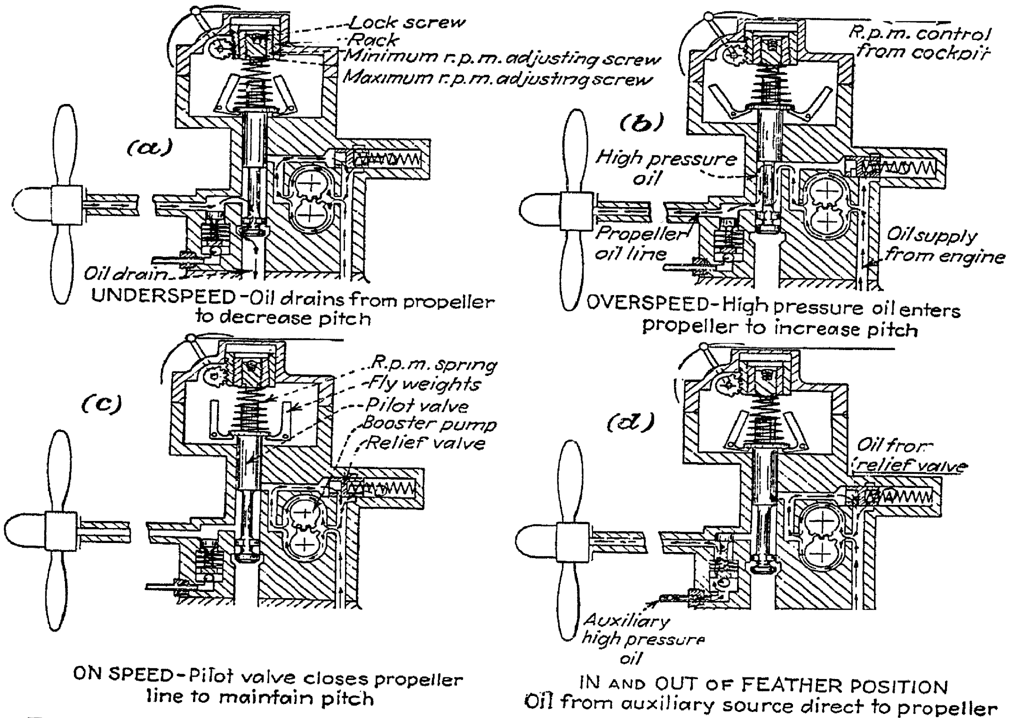


FIG. 280.—This governor is the same as that for the constant-speed propeller except that the auxiliary high-pressure oil inlet is omitted. (*Courtesy of Hamilton Standard.*)

the force of the counterweights, which tend to place the propeller in high pitch. The oil pressure delivered to the piston is regulated by the constant-speed control or propeller governor.

Figure 280 shows a schematic drawing of this governor, and Fig. 281 shows a cutaway. When the pilot selects the r.p.m. desired, by operating the propeller pitch control in the cockpit, he varies the spring tension in the fly-weight type of governor. If the engine slows down, as in part *a*, Fig. 280, the fly weight moves in, lowering the pilot valve. The governor gear pump,

included in the propeller governor to boost the engine oil pressure to 180 to 200 p.s.i., supplies oil to the piston. As the piston moves forward, the pitch angle is decreased and the r.p.m. increased. If the engine "revs up," as in part *b*, Fig. 280, the fly weights move out, raising the pilot valve. This closes the oil passage and forces the governor oil back through the oil relief valve. It also allows the piston oil to drain back to the

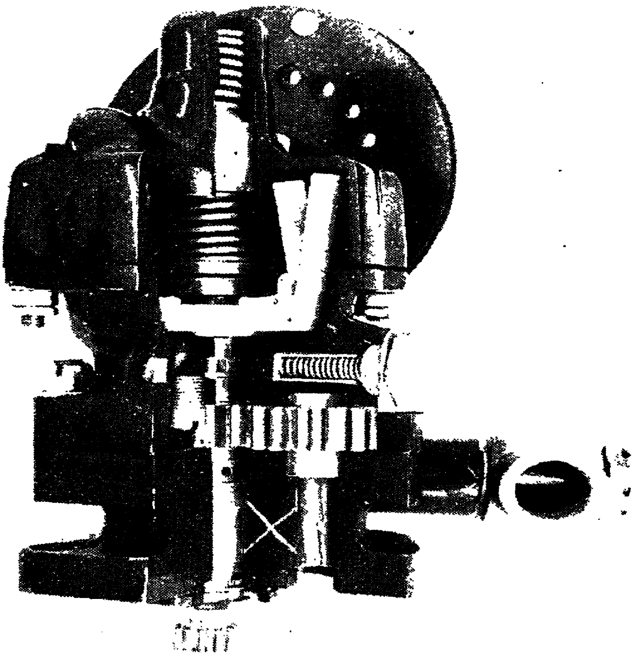


FIG. 281.—Cutaway of a constant speed governor for a Hamilton Standard hydromatic propeller.

engine. The fly weights now increase the pitch and decrease the r.p.m. When the engine is on speed, the governor and pilot valve assume the position of part *c*. This closes the oil passage to the piston, sealing the oil in the piston and forcing the governor to pump oil back through the relief valve. Figure 282 shows a cutaway of a constant-speed propeller.

Full Feathering

A cutaway of the Hamilton Standard full-feathering hydromatic propeller is shown in Fig. 283. An expanded view is

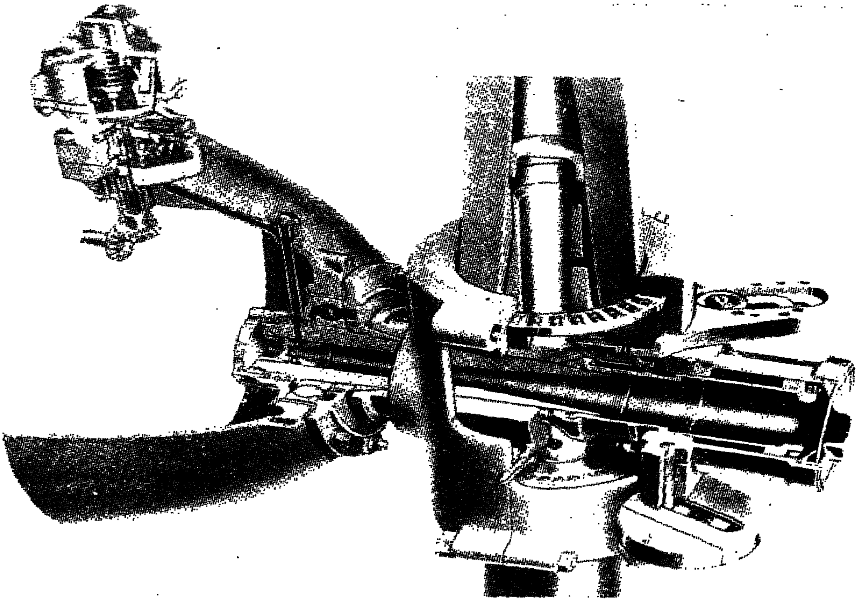


FIG. 282.—A Hamilton Standard constant-speed propeller.

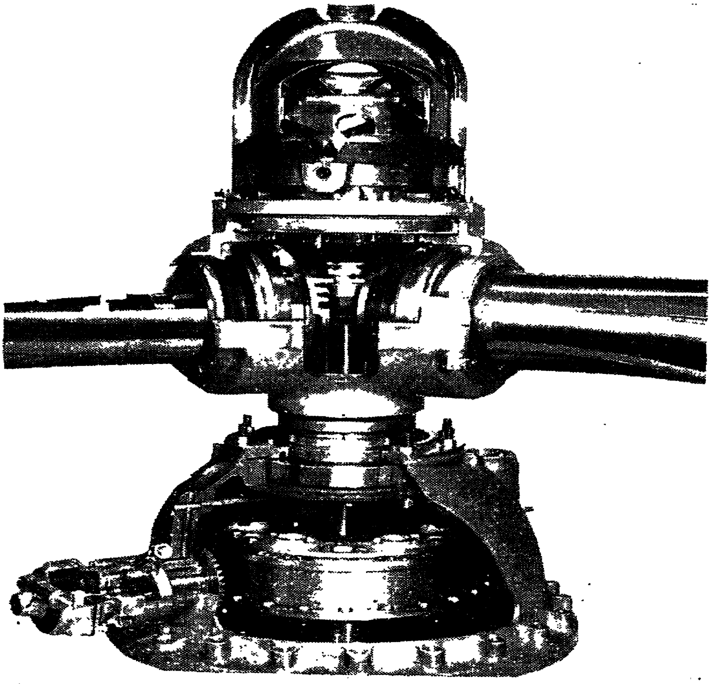


FIG. 283.—Cutaway view of a Hamilton Standard full-feathering hydromatic propeller.

given in Fig. 284. This propeller basically is similar to the constant-speed propeller in structure and operation but does not employ counterweights. The dome, or cylinder, is attached securely to the barrel. The double-acting piston, operating inside this cylinder, translates oil forces into blade-twisting

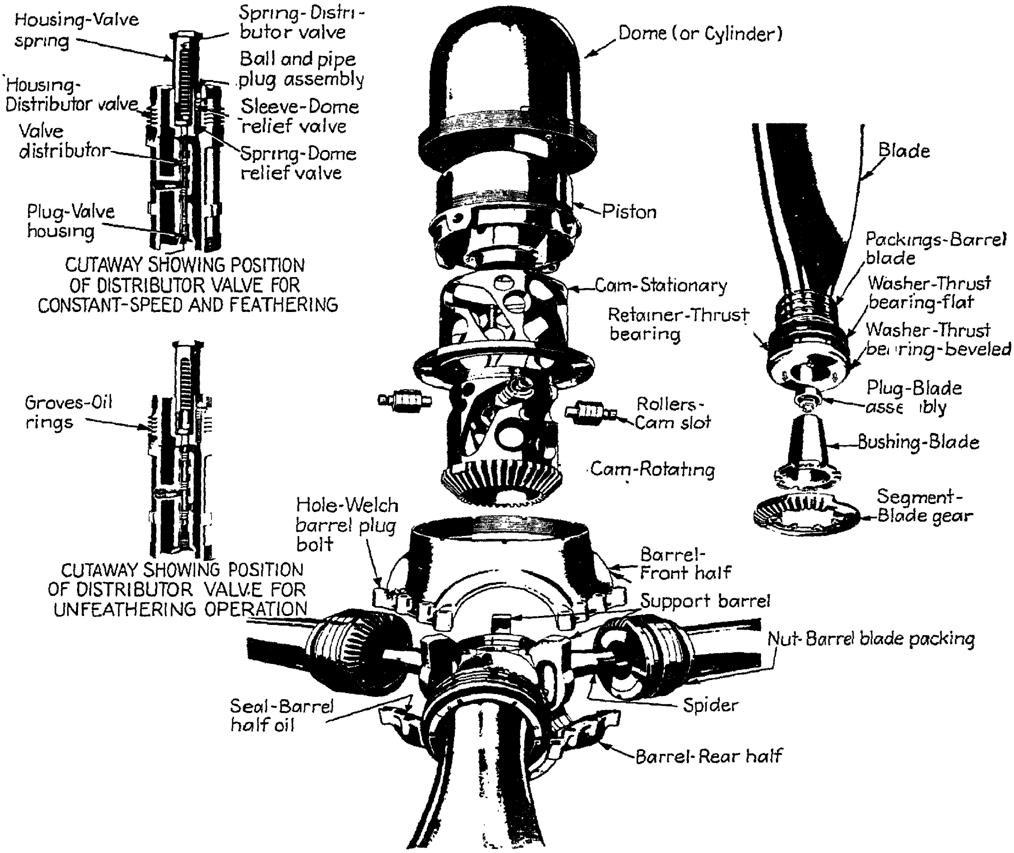


FIG. 284.—Expanded view of a Hamilton Standard hydromatic propeller.

moments by means of two coaxial cams. Figure 285 shows the combined forces acting on the blades. The centrifugal twisting moment of the blades combines with the engine oil pressure on the outboard side of the piston to place the blades on low pitch. Boost oil from the governor acts on the inboard side of the piston to place the blades in high pitch. The distributor valve, located in the center of the piston (see Fig. 286) distributes pressure oil

either to the inboard or to the outboard side of the piston and returns the other oil to the system. During constant-speed

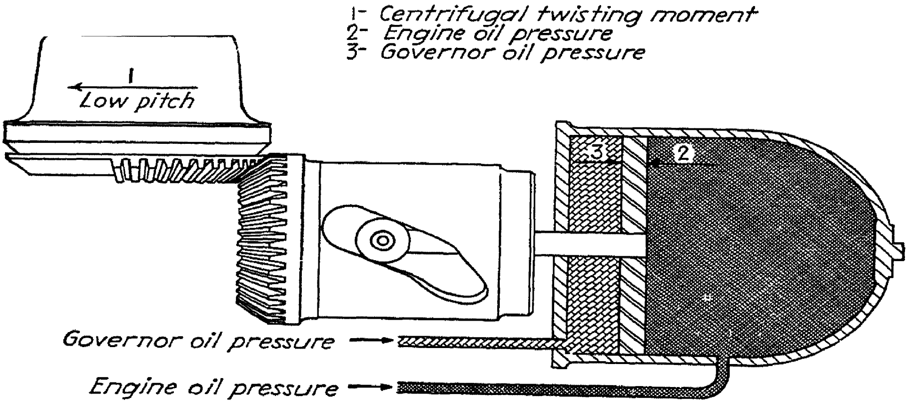


FIG. 285.—Diagram of full-feathering-propeller control forces.

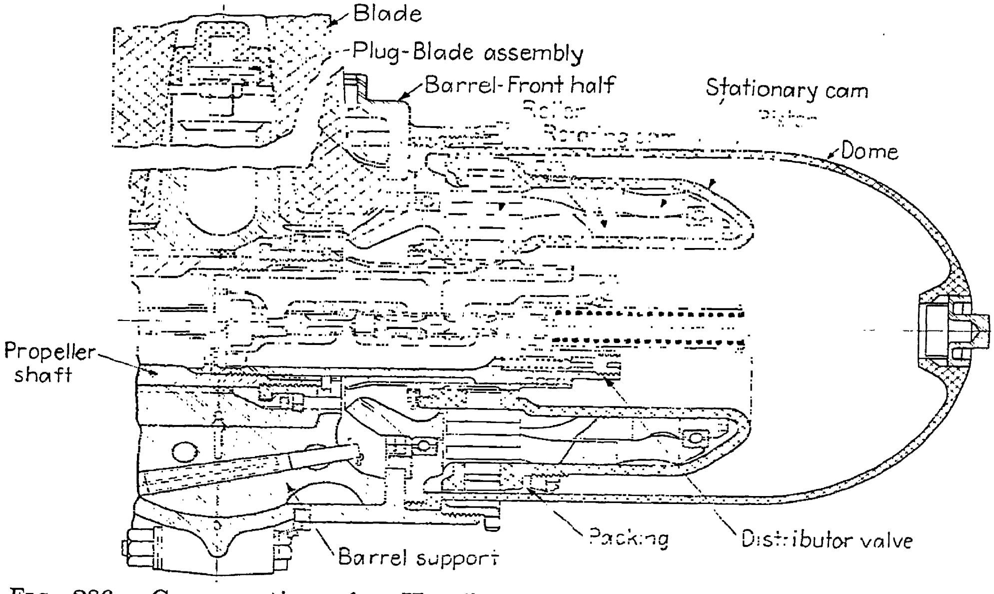


FIG. 286.—Cross section of a Hamilton Standard full-feathering hydromatic propeller.

operation the governor action is the same as for the constant-speed propeller (Fig. 280). Figure 287*a* shows the path taken by the oil to supply pressure for constant-speed operation.

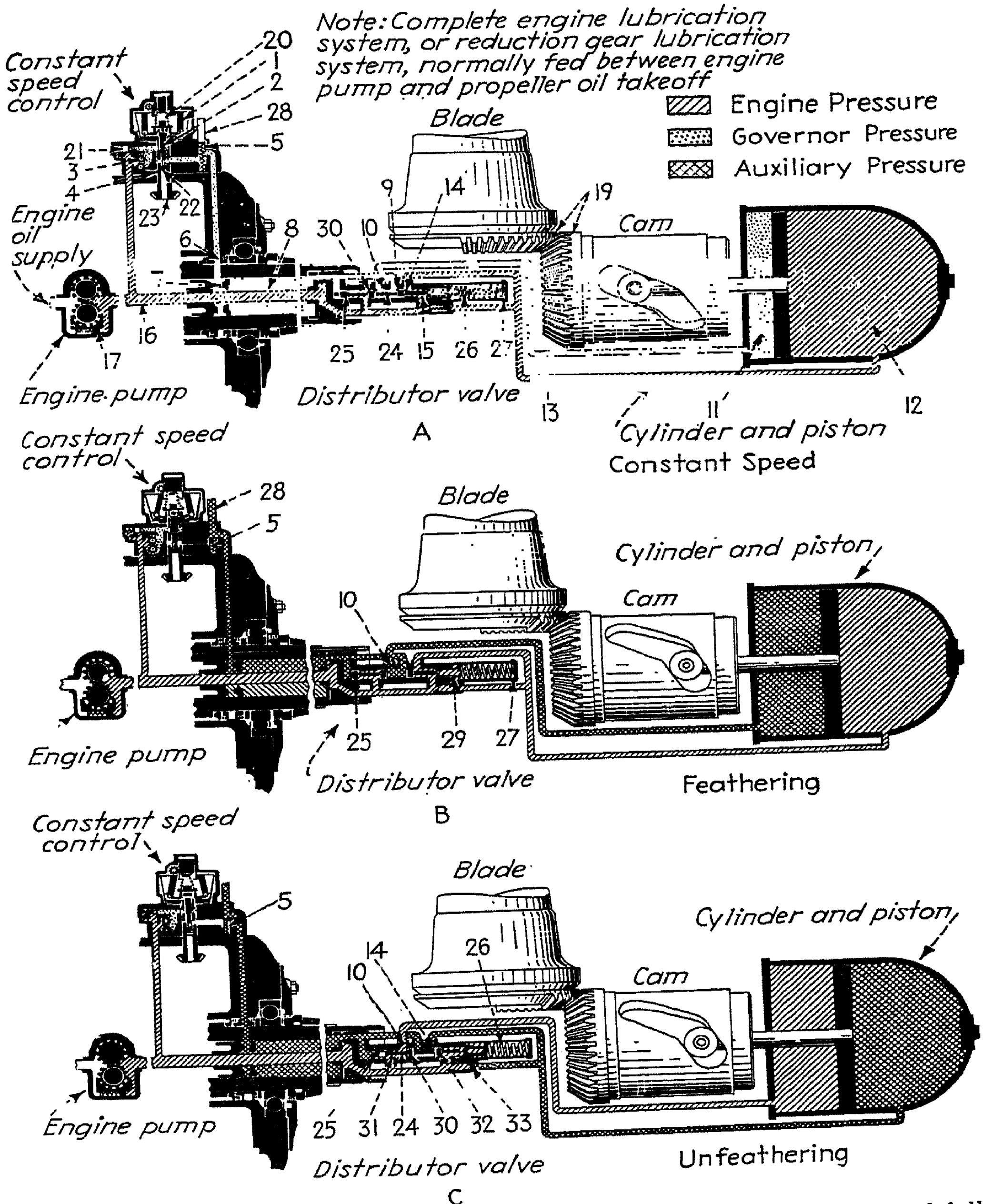


FIG. 287.—Schematic diagram of the oil passage for a Hamilton Standard full-feathering propeller.

When the propeller is feathered (Fig. 287*b*), the same passage of the distributor valve used to furnish governor oil to the inboard side of the piston is used to furnish high-pressure oil from the external full-feathering pump to force the piston full forward. The engine oil on the outboard side of the piston returns to the system in the usual manner. Oil through the governor takes the path shown in Fig. 280*d*.

To unfeather the propeller, the function of the distributor valve is reversed (Fig. 287*c*). This is done by collapsing the distributor valve spring and supplying external oil pressure to the outboard side of the piston and returning oil to the engine from the inboard side. If the engine is rotating, the action of the governor will complete this process after the propeller has reached approximately 1,200 r.p.m.

ELECTRICALLY OPERATED PROPELLER

The Curtiss electric propeller is operated by means of an electric motor attached to the propeller hub in a manner similar to the hydromatic operating cylinder. The blades on this propeller may be either forged aluminum alloy or steel. The operating power is supplied to the motor by the plane's electrical system through brushes mounted to the engine nose section to slip rings mounted on the rear of the propeller hub. Instead of a piston, a reversible motor through a gear reducer operates a bevel gear. This bevel gear meshes with one on the blades to give blade rotation. Constant-speed control is maintained by a fly-weight governor located on the nose section of the engine. Instead of supplying oil under pressure it supplies current in the desired direction, to correct for change in engine r.p.m. A manual control makes possible the selection of any fixed-pitch position and offers added reliability. A motor brake is incorporated in the motor to stop it from rotating at once in case the pitch current is cut off. It also prevents the blade twisting moment from changing the pitch.

Figure 288 shows a propeller assembly, and Fig. 289 gives a schematic diagram of the propeller governor. Electrical switches are added for high- and low-pitch stops. In addition, a mechanical low-pitch stop is installed to prevent the blades from flattening out in case of switch failure. Feathering is accomplished by a separate circuit that by-passes the high-pitch switch.

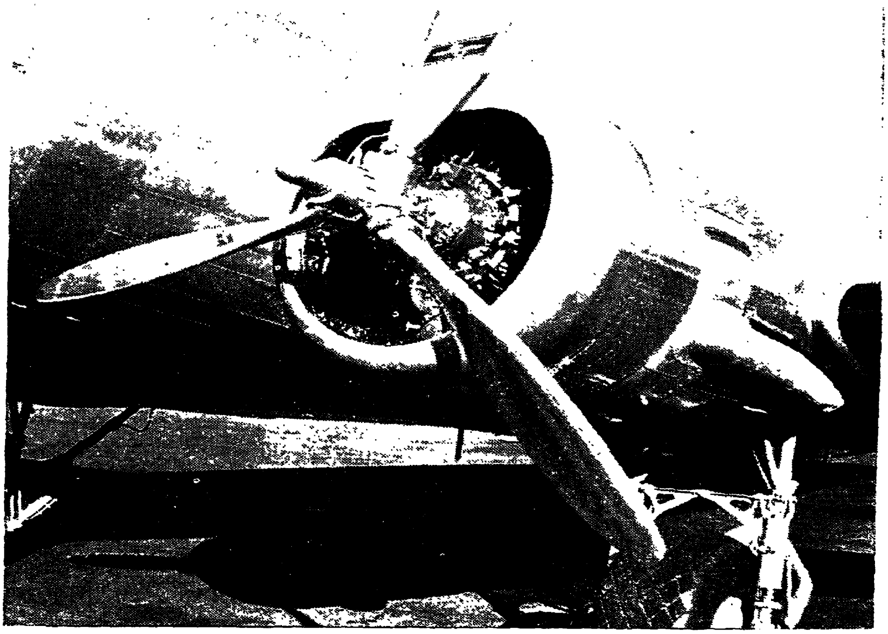


Fig. 288.—A Curtiss electric propeller installed on a Douglas DC-3.

PROPELLER MAINTENANCE

Wooden Propellers

Wooden propellers should be inspected before each trip for cracks, cuts, safety devices, and loose tips. At each periodic inspection they should be more thoroughly inspected for warp, delamination, loose screws, rivets, tipping, solder, elongated bolt holes, track, etc.

Track can be checked by placing a pointer on a box near the tip. The propeller is rotated to determine if both tips are in the same plane. If they are out more than $\frac{1}{8}$ in., the propeller must be replaced.

Although the wooden propeller is much cheaper than the metal propellers, its service life is much less if the protective coating

is not maintained. When the protective coating needs replacing, the propeller should be removed, refinished, and rebalanced. A good grade of clear varnish can be used for this.

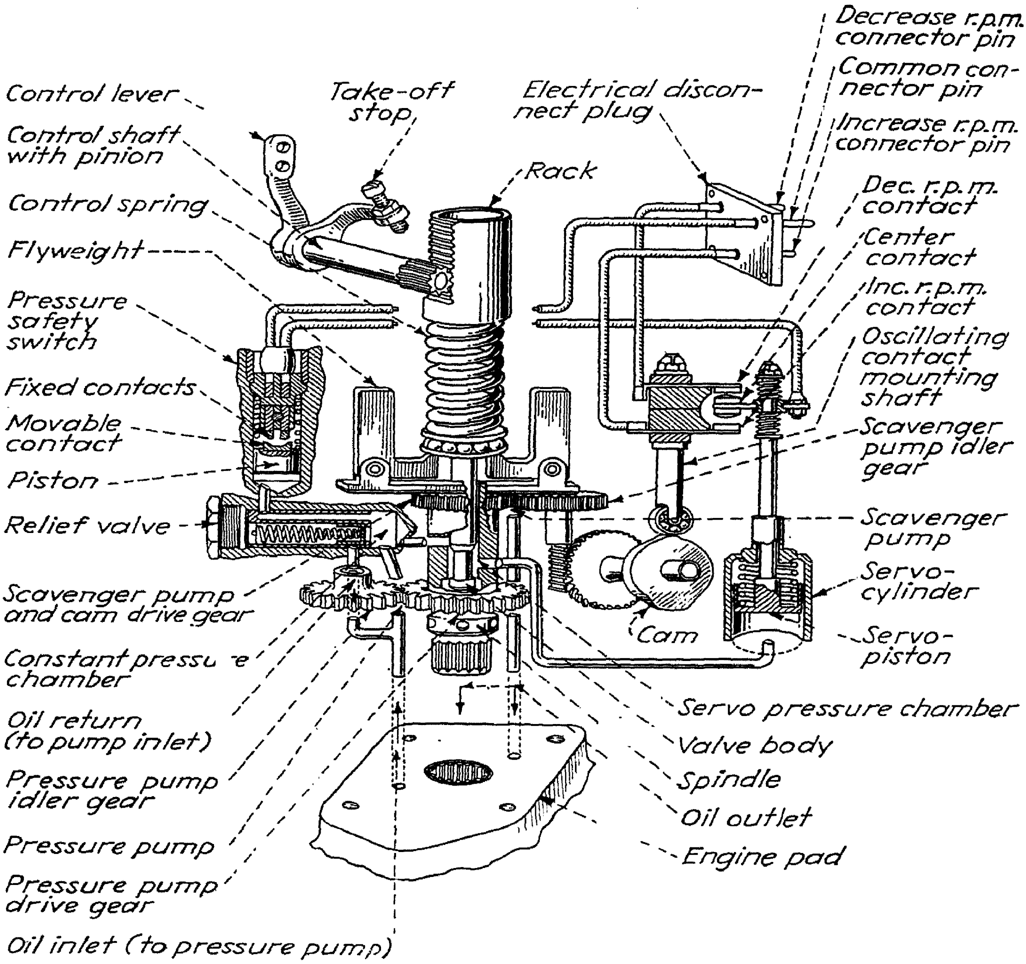


FIG. 289.—Schematic diagram of a Curtiss electric propeller governor.

The CAA pamphlet, *Repair and Alteration Manual* 18, gives a thorough discussion of the repair, refinishing, and balancing of wooden propellers.

Metal Propellers

Metal propellers, like wooden propellers, should be inspected before each flight or once a day for cracks, nicks, oil leaks, etc.

Since metal propellers are manufactured from a more durable material, the labor of servicing of these propellers is very slight. At periodic inspections a more thorough check is made. If counterweights are used, they should be greased with the proper lubricant. Full-feathering propellers operate in oil and so do not require periodic lubrication. Safety devices, such as cotter keys, snap rings, etc., should also be inspected. If dents or

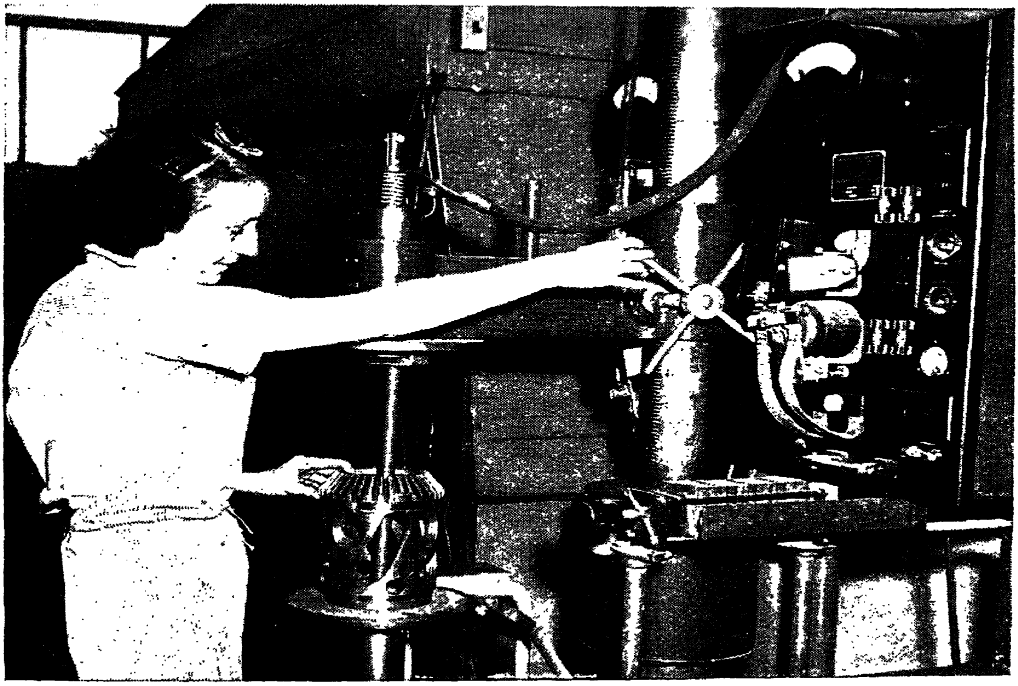


FIG. 290.—Magnafluxing a cam of the hydromatic propeller. (*Courtesy of Eastern Air Lines, Inc.*)

nicks on the face or leading edge of the blades are severe, they should be removed by rounding out the dents to relieve strain. This should not be attempted by an inexperienced student. Again the CAA pamphlet, *Repair and Alteration Manual* 18, may be consulted for detailed information.

After a final check, the engine should be run up and the propeller operated several times to ensure proper control. Any adjustments found necessary should be made. If the propellers on multiengine aircraft will not remain synchronized, the domes should be removed and cleaned. Sludge collecting in the dome

often prevents satisfactory operation. If excessive oil leaks are noted on the dome, the seal should be replaced.

Overhaul

Overhaul is a specialist's job and is beyond the scope of this book. In general, however, the propeller is removed after a specified number of service hours and routed to the propeller shop for overhaul. Here the propeller is completely disassembled, cleaned, and inspected. All steel parts are checked for wear and magnafluxed for cracks. Parts worn beyond limits or cracked are discarded. The aluminum blades are dipped in an etching solution and checked for cracks with a magnifying glass. Aluminum parts that cannot be repaired are discarded. Small cracks, bends, cuts, and dents that come within the allowable limits are removed. The blades are buffed and polished, and the propeller is assembled for use. Figure 290 shows the magnafluxing of a hydromatic propeller cam.

CHAPTER VIII

V-TYPE ENGINE PRINCIPLES

GENERAL

This chapter is written to familiarize the student with the principles of engine operation, not to serve as a text for maintenance, repair, or overhaul procedures, which require specialized training available in advanced courses.

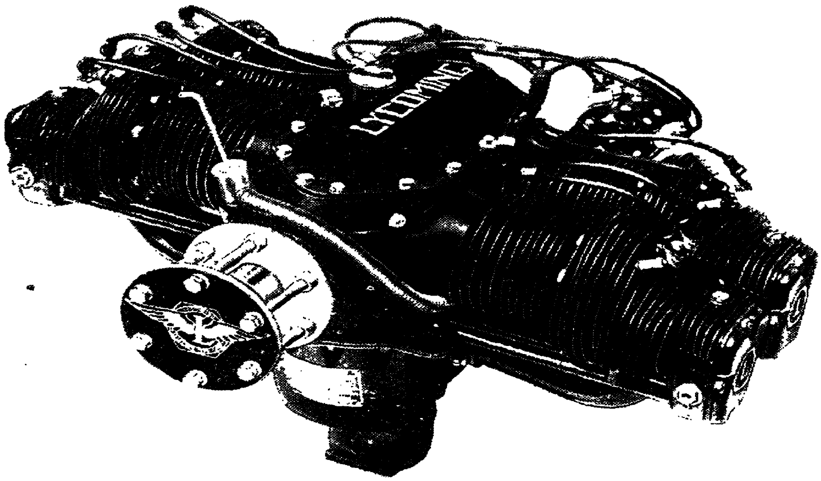


FIG. 291.—Sixty-five horsepower Lycoming-opposed engine used in light aircraft.

Engines are classified according to method of cooling, which may be liquid or air; cylinder arrangement, which may be in line, opposed, or radial; and cycle of operation, which may be two- or four-stroke cycle. The most popular type of engine in the United States is the air-cooled four-stroke-cycle radial engine. In-line liquid-cooled engines are used in Army fighter planes. In-line air-cooled engines are used on planes of the middle-price field, and opposed air-cooled engines are used in the low-price field.

In-line engines are those whose cylinders are arranged in a line, as in automobile engines. These engines may be inverted,

with the cylinder below the crankcase. Opposed engines have their cylinders opposite each other on the crankcase. Radial engines have their cylinders located on a circle around the crankcase. Radial engines may be single or double row. In the latter case, the second row is staggered.

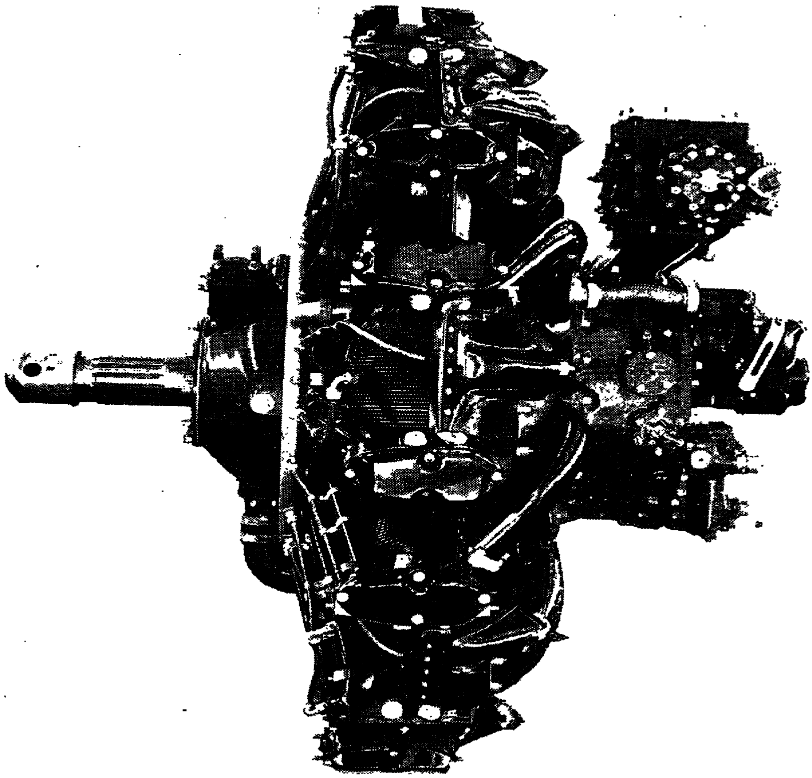


Fig. 292.—Side view of a Wright Cyclone radial air-cooled engine.

PRINCIPLES OF OPERATION

The four-stroke-cycle airplane engine, commonly called the *four-cycle engine*, is used in the United States. Some two-cycle airplane engines are manufactured in Europe. The principle of operation of any four-cycle engine is the same, no matter how large it may be or how complex. Therefore, it is necessary to learn these principles before engine operation can be appreciated.

The airplane engine is classified as an internal-combustion engine because the conversion of heat energy to mechanical energy takes place inside the engine itself. Figure 294 shows the parts of a typical internal-combustion engine in a simplified form.

The up-and-down motion of the piston, operating inside the cylinder, is converted into rotary motion by means of a con-

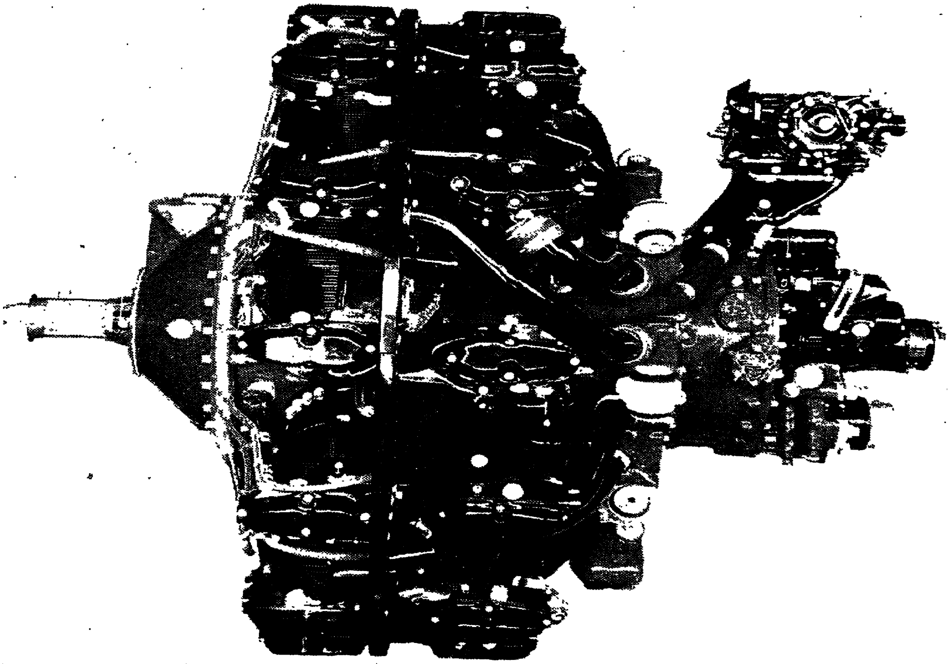


FIG. 293.—Side view of a twin-row, 14-cylinder, 1,500 hp. Wright engine.

necting rod between the piston and the crankshaft. As the crankshaft rotates, it operates two cams through a cam gear train. The cams raise and lower cam followers, push rods, and rocker arms. This raising and lowering of the rocker arms opens and closes the intake and exhaust valves to admit the gasoline and air mixture and to exhaust the burned gases. The carburetor connected to the gasoline supply meters the gas in correct proportions with the incoming air. The magneto, operated by another gear train, supplies the spark to the spark plug. A gear type of oil pump furnishes lubricating oil to the system,

and a scavenger pump picks up all excess oil and returns it to the oil tank.

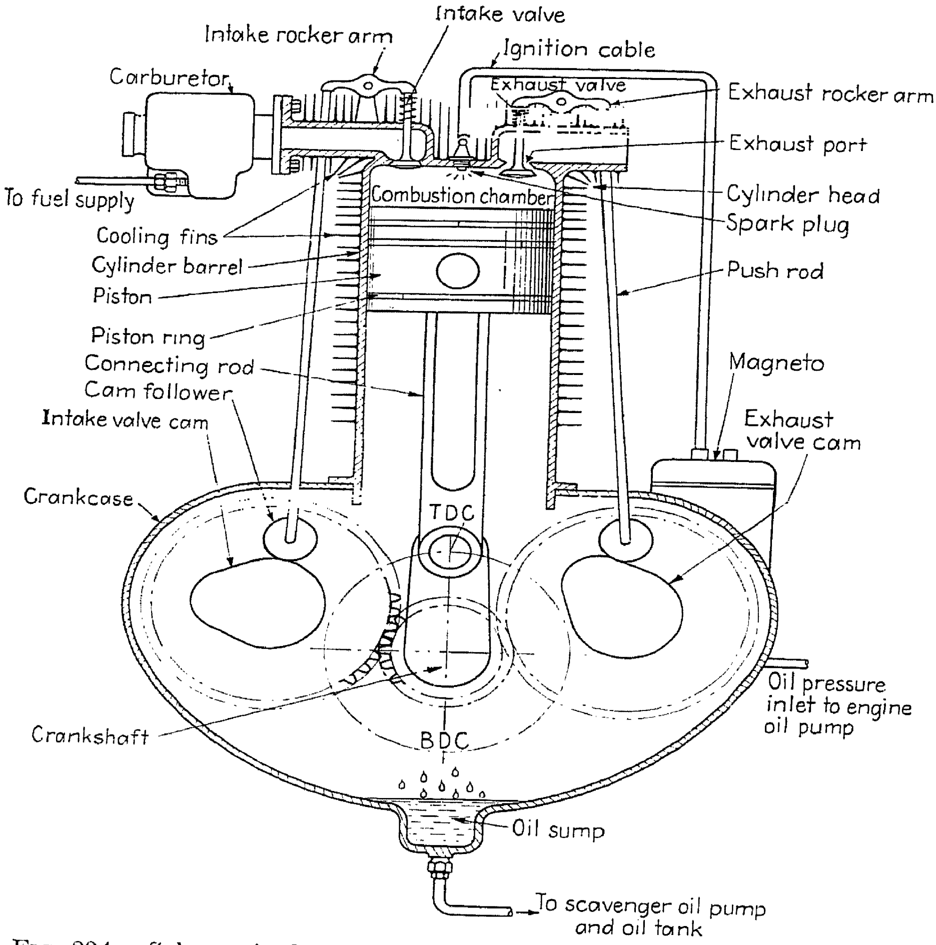


FIG. 294.—Schematic drawing of a simple internal-combustion engine.

FOUR-STROKE CYCLE

Since the four-cycle engine is the only one used in aircraft in the United States, it will be the only one described here. Figure 295 should be consulted during the discussion.

Intake Stroke.—The first stroke of the four-stroke cycle is the intake. During this stroke the piston moves down, decreasing the air pressure inside the cylinder. As the piston moves down, the intake valve opens and the gas-air mixture is forced

into the chamber by atmospheric pressure. When the piston reaches the bottom of the stroke it is said to be at *bottom dead center* (B.D.C.). The intake valve now begins to close, for the cylinder is almost fully charged.

Compression Stroke.—As the crankshaft continues to rotate, the intake valve closes and the piston moves up, compressing the mixture in a small space at the top of the cylinder. This space is called the *combustion chamber*. The intake valve did not close until after the B.D.C. to allow additional mixture to enter the cylinder while the piston travel is still small. During this stroke this mixture is compressed and is therefore called the

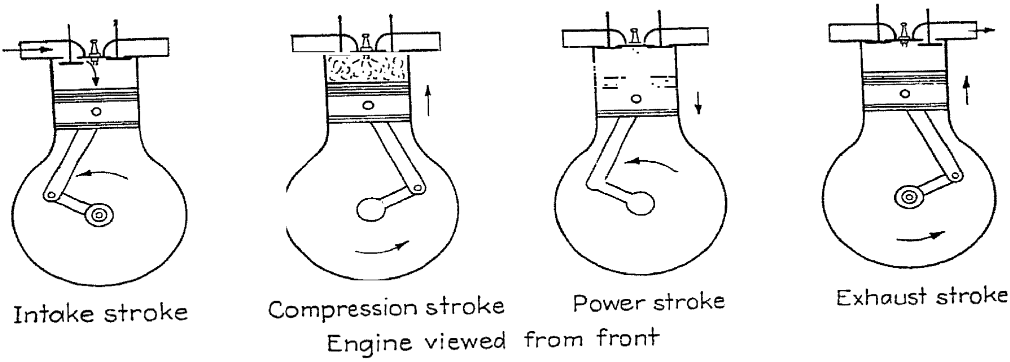


FIG. 295.—Internal-combustion engine, 4-stroke cycle.

compression stroke. Just before the piston reaches the top of its stroke the spark plug is fired by the ignition system. This is done to allow a larger portion of the gases to be consumed during the next stroke. When the piston reaches the top of its stroke, it is said to be at *top dead center* (T.D.C.).

Power Stroke.—As the gases continue to burn, they expand and force the piston down. This stroke is called the *power stroke* and is the only stroke out of the four that delivers power. As the piston approaches B.D.C., the exhaust valve opens to allow more time for the burned gases to escape. This is necessary to keep the dilution of the new charge with burned gas to a minimum and is considered well worth the small loss of power.

Exhaust Stroke.—As the piston passes B.D.C. and starts up, it begins its final or exhaust, stroke. During this stroke the burned gases are forced out the exhaust port to make way for a new charge. Just before the piston reaches T.D.C. the intake

valve opens. This allows the fresh charge to enter the cylinder and helps force the burned gases out the exhaust port. When the piston reaches T.D.C., the fourth stroke of the cycle has been completed and the cycle begins again.

The entire operation has required four strokes of the piston, two up and two down. During this operation the crankshaft has made two complete revolutions. Since all other cylinders are connected to the same crankshaft, the same operations have been going on in them, but not at the same time. However, all cylinders must fire and deliver power each two complete revolutions, or 720° of crankshaft travel. Therefore, if the engine has four cylinders, one must fire each 180°.

In the above discussion the valves opened before T.D.C. and B.D.C. This is known as *valve lead* and is measured in degrees of crankshaft rotation. The opening or closing of the valve after T.D.C. or B.D.C. is called *valve lag* and is also measured in degrees of crankshaft rotation. It was stated above that the intake valve opened before the exhaust valve closed. The amount of crankshaft travel in degrees during which both valves remain open at the same time is called *valve overlap*. The amount of valve lead, lag, and overlap is a very important item in the proper functioning of the engine.

The number of degrees of crankshaft travel the ignition system is timed to operate before T.D.C. is known as *ignition advance*. This is also an important item in the proper functioning of the engine.

The order in which cylinders are fired is called *firing order*. This order varies with different types of engine. In general, to eliminate vibration, the firing order is arranged so that two adjacent cylinders do not fire in succession.

The firing order of a six-cylinder in-line engine may be 1-5-3-6-2-4, where cylinder 1 is the cylinder next to the propeller. The firing order of a four-cylinder opposed engine may be 1-3-2-4, where cylinders 1 and 3 are on one side and cylinders 2 and 4 are on the other side.

Single-row radial engines always have an uneven number of cylinders. Cylinder 1 is the top cylinder. The rest of the cylinders are numbered counterclockwise when the engine is viewed from the front. By firing every other cylinder in order of rotation, beginning with 1, all the odd cylinders will fire the

first revolution and all the even cylinders will fire the second revolution. On the third revolution cylinder 1 will again fire first.

The twin-row radial engine has two separate rows of cylinders of an odd number of cylinders each, operating two separate crankshafts 180° apart. All the rear cylinders have odd numbers, and all the front cylinders have even numbers. The firing order for a double-row 14-cylinder Wright Cyclone is 1-10-5-14-9-4-13-8-3-12-7-2-11-6. If the double rows are broken down into two separate engines whose crankshafts are 180° apart, the rule given for the firing order of the single row still applies. The cylinder order of the rear row is 1-3-5-7-9-11-13. By firing every other cylinder the firing order will be 1-5-9-13-3-7-11. This is the same order given above. The front row of cylinders have all even numbers; but since the crankshafts are 180°, cylinder 8 on the bottom will be the first cylinder. The cylinder order will be 8-10-12-14-2-4-6, and the firing order will be 10-14-4-8-12-2-6. The two rows are combined to get the firing order given above.

ENGINE PARTS

In-line and V Engines

Cylinders.—Cylinders are comprised of two parts, the barrel and the cylinder head. In liquid-cooled engines all the cylinder barrels for each bank are cast in one solid block, with space around the barrels for the liquid coolant. The cylinder heads in which are housed the valve guide, valve, valve springs, and rocker arms if used are cast in a separate block and bolted to the first one. The cylinder blocks are cast aluminum with steel inserts. The heads are also cast aluminum.

Air-cooled cylinders have steel barrels and cast or forged aluminum heads. Each cylinder is manufactured separately. As in the liquid-cooled engine, the cylinder head of an air-cooled engine houses the valve and valve mechanism. Both the head and the barrel have fins to radiate heat to the air.

The valve slides up and down in the valve guide, located in the cylinder head, and is held against the valve seat by valve springs, a split cone, and a washer (see Fig. 296). Two or three steel springs are used. They are coiled in alternate directions to equalize the pressure against the valve stem. A wire safety

clip is placed in a groove just below the cone to prevent the valve from dropping into the cylinder should the locking device or the springs fail. The valve is manufactured from austenitic, tungsten, or chrome-nickel steel. Some exhaust valves in large-horsepower engines have sodium inside the valve stem to help conduct the heat away from the valve head.

Forged aluminum-alloy pistons move up and down inside the cylinders. Because the cylinder barrel is steel and the piston aluminum, the expansion of the two with heat will be different.

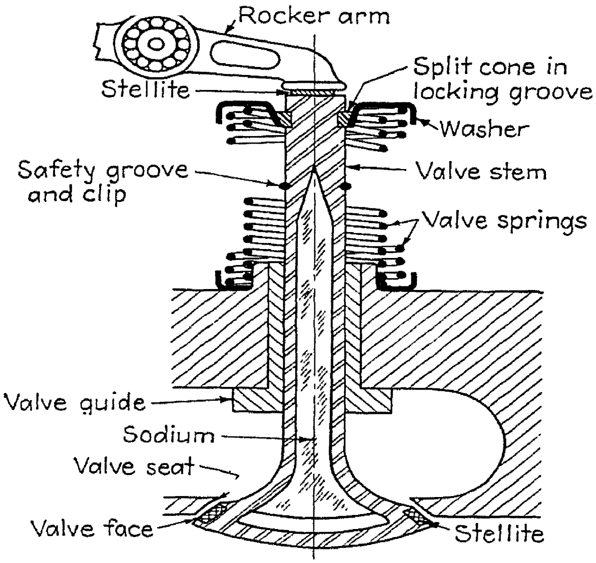


FIG. 296.—Schematic drawing of a typical valve installation.

If the piston is made to give good compression at normal operating temperature of the engine, it may freeze at higher temperatures or loose compression at cold starting. In order to take care of the expansion and any wear that will normally result with use, piston rings are used. They may vary from three to six rings per piston and are manufactured from a high-grade cast iron, fitted into grooves in the piston. Rings are of two general types, compression and oil. Rings also transfer heat from the piston to the cylinder walls, where it can be dissipated to the cooling medium.

Crankshaft and Camshaft.—The crankshaft of an in-line engine runs the entire length of the engine and is bolted to the

crankcase by means of split bearings. On the single-bank engines all cylinder connecting rods have a separate crank. The angle of variation between the cranks will depend on the number of cylinders. If the engine is a V type engine (an engine whose banks make an angle of 30 to 90°), the same crank is used for two cylinders; that is, the two cylinders just opposite operate off the same crank. This may be accomplished by means of a master rod and an articulating rod (see Fig. 297). The articulating rod is fastened to the master rod with a knuckle pin, which permits the two rods to operate separately. The forked- and blade-rod combination is also used. This permits the blade rod to operate between the fork.

The valves are operated by camshafts running parallel to the crankshaft. In some engines they are located in the crankcase and operate cam followers and push rods, which in turn operate the rocker arms. In other engines the camshaft runs on top of the cylinder heads and operates the valves by direct contact. This eliminates the rocker arms, the push rods, and the cam follower. The overhead shafts are rotated by tower shafts running up the back of the engine from the crankshaft. Since all cylinders must fire in two revolutions, all valves must operate once every two revolutions. Therefore, the camshaft is geared to turn at one-half crankshaft speed.

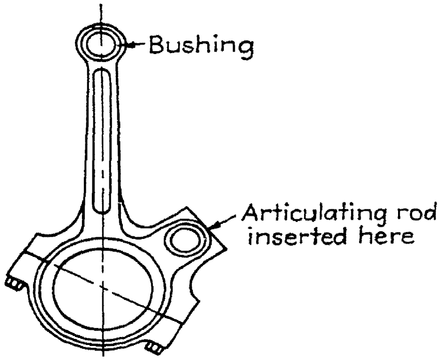


FIG. 297.—Master rod for a V-type engine.

Crankcase.—Crankcases on most in-line and V-shaped engines are split horizontally in the center of the crankshaft bearings. They are of cast aluminum alloy bolted together. The cylinders or cylinder block and accessories are attached to the crankcase, which in turn is attached to the engine mount.

OPPOSED ENGINE

Cylinders.—This type of engine is very popular in the low-price field because it is compact and relatively simple to maintain. The cylinders are located on opposite sides of the crankcase and may be vertical or horizontal. The latter arrange-

ment is used in this country. Cylinders are manufactured in the same manner as the cylinders for the in-line engine. The valve mechanism is contained in the head and is operated by push rods.

Crankshaft and Camshaft.—Although the cylinders are located on opposite sides of the crankcase, they are staggered so that each cylinder connecting rod has a separate crank. One camshaft, located just below the crankshaft and parallel to

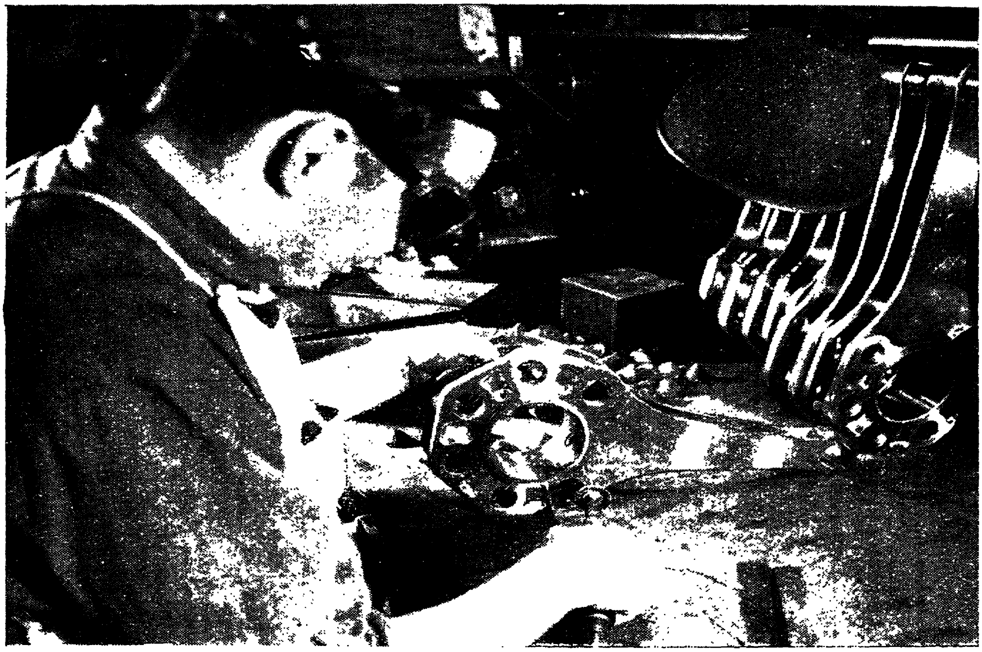


FIG. 298.—Putting the finishing touches to a master rod. (*Courtesy of Wright Aeronautical Corp.*)

it, operates both sets of valves. Like the in-line engine it rotates at one-half crankshaft speed.

Crankcase.—The crankcase is a cast-aluminum shell split vertically through the center of the bearings to receive the crankshaft, camshaft, and the cam followers. The accessories are bolted to the rear of the case. Some low-priced engines have a wet sump where the oil is contained inside the crankcase.

RADIAL ENGINE

Cylinders.—In this country, the radial type is by far the most prominent widely used engine. It varies from 125 to

3,000 horsepower. Because of its form of construction it must be air-cooled. The cylinders are manufactured like the air-cooled engines previously discussed and are bolted to the crank-case like spokes on a wheel. On twin-row engines the rear cylinders are located between the front cylinders for improved design and better cooling. All radial engines have the valve in head mechanism operated by push rods and rocker arms.

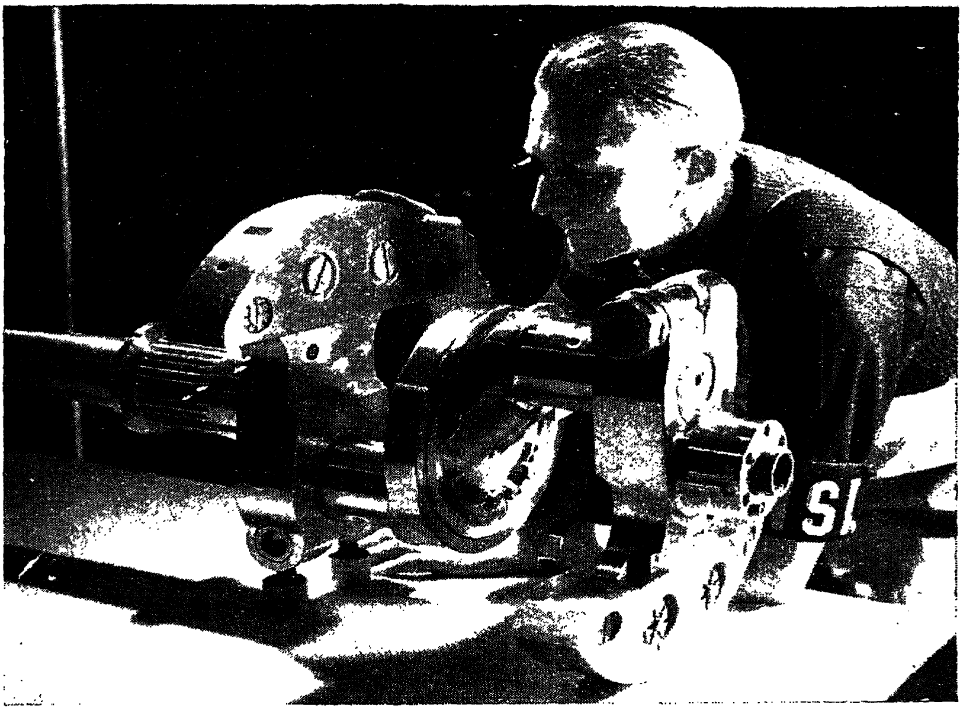


FIG. 299.—Making the final visual inspection of a double-row crankshaft with a jeweler's glass. This is a crankshaft for a 1,700-hp. engine. (*Courtesy of Wright Aeronautical Corp.*)

Crankshaft and Camshaft.—Because all cylinders are in the same plane a single-throw crank is used, and thus all connecting rods must operate off the same crank. This is accomplished by means of a master rod and additional articulating rods for each cylinder. A master rod is shown in Fig. 298. As stated earlier, the crank throw on a double-row engine is 180° apart. In this case, two master rod assemblies are used, one for each row. Figure 299 shows the crankshaft of a twin-row engine.

The radial engine does not use a camshaft but employs cam gears or a cam drum operated by the crankshaft through appropriate gear trains. The hardened steel drum is located in front of the power section and has two tracks of cam lobes spaced around its outer circumference. One row of lobes operates the

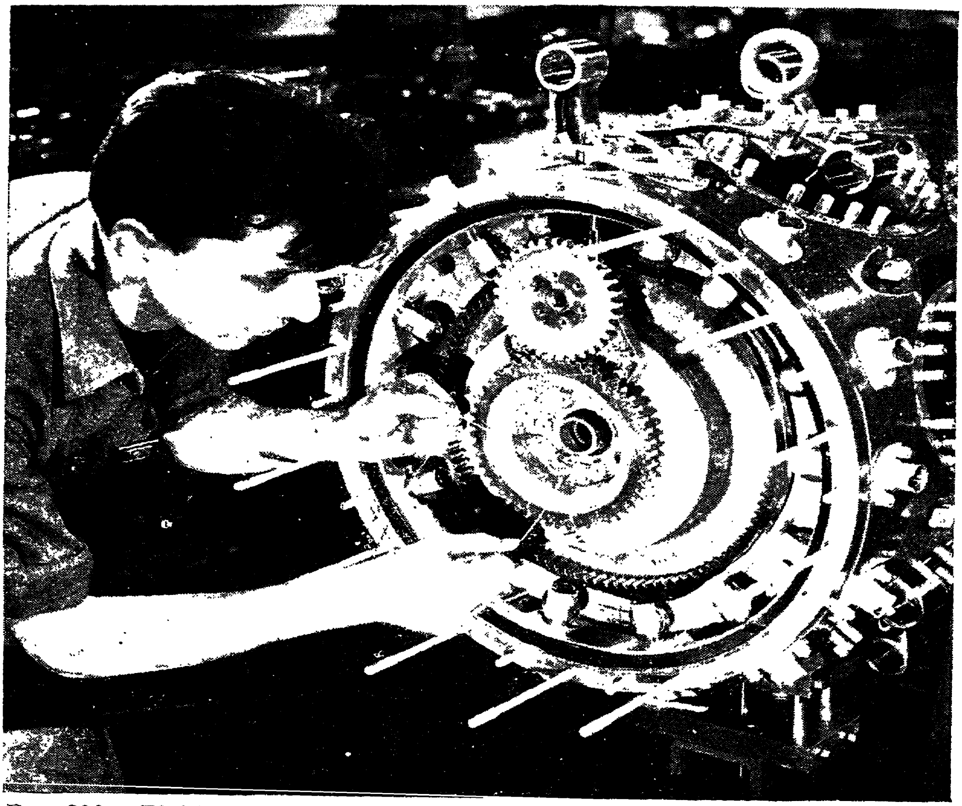


FIG. 300.—Finishing up the cam-ring installation on the rear crankcase of a double-row Wright engine.

exhaust-valve cam followers, and the other row operates the intakes. This cam ring is shown in Fig. 300. There may be three, four, or five lobes on the cam ring, depending on the engine. In this case, the cam ring rotates, not at one-half crankshaft speed, but at a speed equal to

$$\frac{1}{2} \times \frac{1}{\text{no. of lobes}}$$

For a three-lobe cam ring, this would be one-sixth of crankshaft speed.

Crankcase.—The crankcase on a radial engine is divided into several sections, appropriately designated. The *nose section* is the first section. In this the cam ring, the cam follower, and

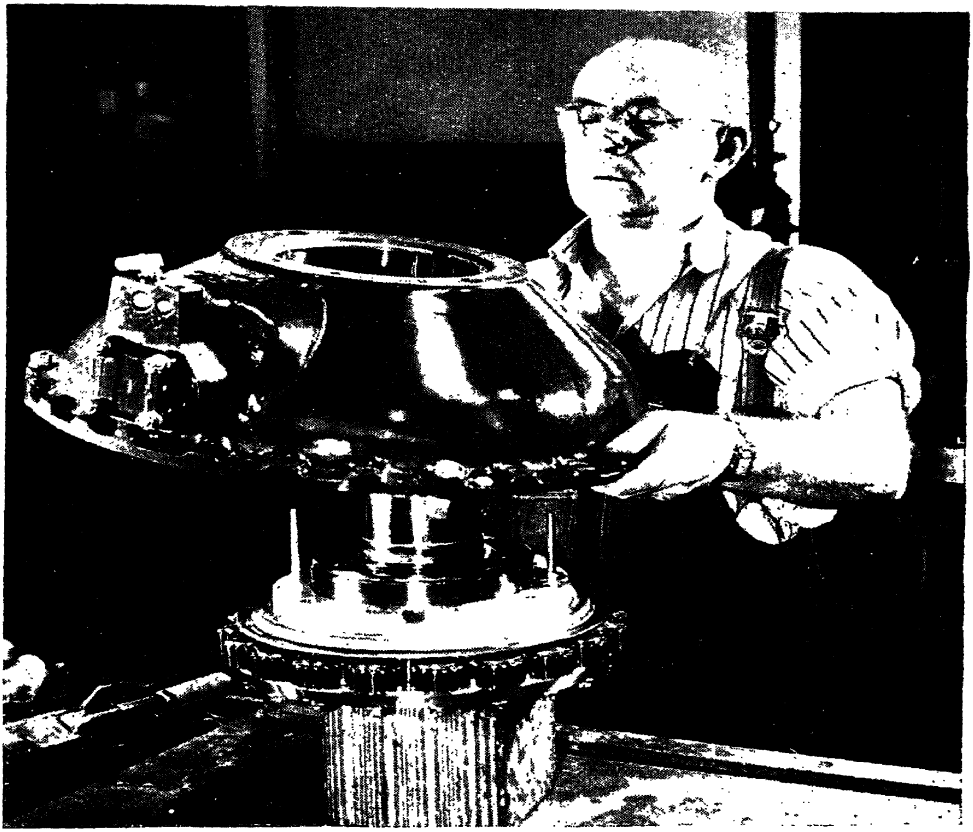


FIG. 301.—Fitting the reduction gears into the nose section. (*Courtesy of Wright Aeronautical Corp.*)

reduction gears, if used, are found. The propeller governor may be attached to the nose (Fig. 301).

The next section is the *power section*, which contains the crankshaft and the connecting rods. The cylinders are also bolted to this section. The double-row engine is principally the same but has two power sections, with a cam ring in front and back. Figure 302 shows the assembly of the power sections of a double-row engine.

The *diffuser section* bolts to the back of the power section and contains the impeller. The purpose of the diffuser section is to direct the fuel mixture to the cylinder intake pipes. The mounting brackets for the engine are also on this section.

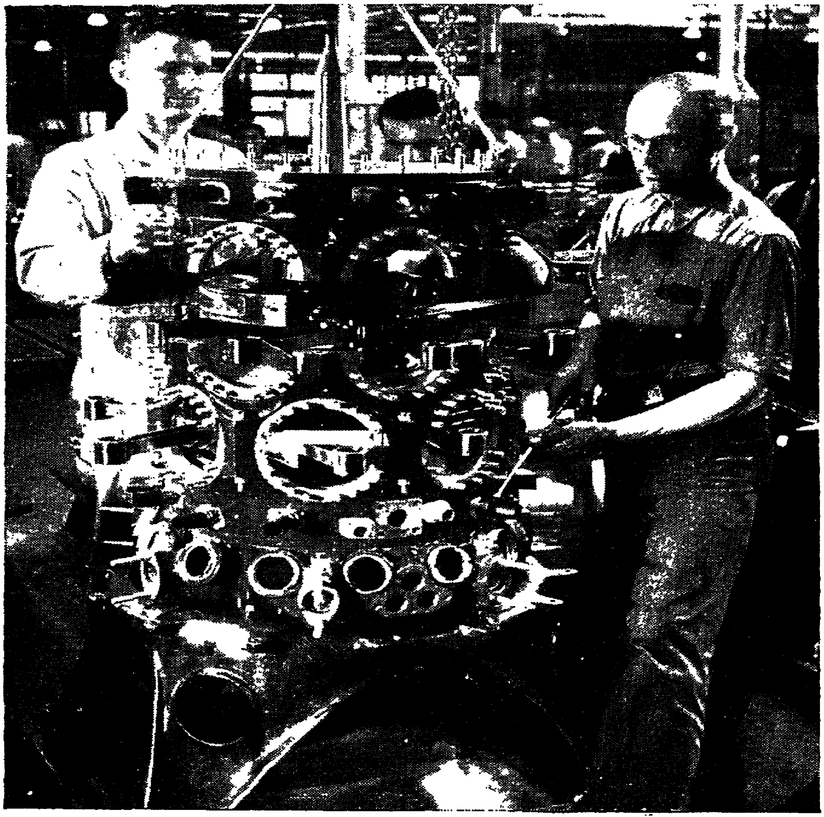


FIG. 302.—Assembling the power section of a double-row Wright engine.

The *accessory section* bolts to the diffuser section and houses all the gear trains for driving the accessories, as magneto, generator, and starter (see Fig. 303).

Figure 304 shows a cross-section of a complete twin-row engine, with accessories and many of the internal parts.

AIRCRAFT ENGINE SYSTEMS

FUEL SYSTEM

The airplane's fuel system may be either a gravity system or a pressure system. Low-priced airplanes employ the gravity

system. In these planes the fuel tank is placed high enough above the carburetor level to ensure a positive flow of fuel under sufficient pressure for all normal attitudes of flight.

Airplanes with the pressure system may have their fuel tanks located either above or below the carburetor level, because fuel

FIG. 303.—Assembling a supercharger rear section. The cover plate to which the accessories are attached can be seen on the table, along with the impeller.

is delivered to the carburetor under pressure from an engine-driven pump. A fuel relief valve is installed in the line to return to the fuel pump or the fuel tank all excess fuel not used by the carburetor. Hand pumps, better known as *wobble pumps*, or electrical fuel pumps are installed in the line to furnish pressure to the carburetor for engine starting or for emergency operation. Strainers are placed in both systems to collect water and foreign matter. A typical fuel system for a multiengine plane is given

in Fig. 305. If more than one tank is used, selector valves are installed to permit use of all tanks for either engine. On multi-engine craft, cross-feed valves are installed to permit the use of either engine pump for the other engine should one pump fail.

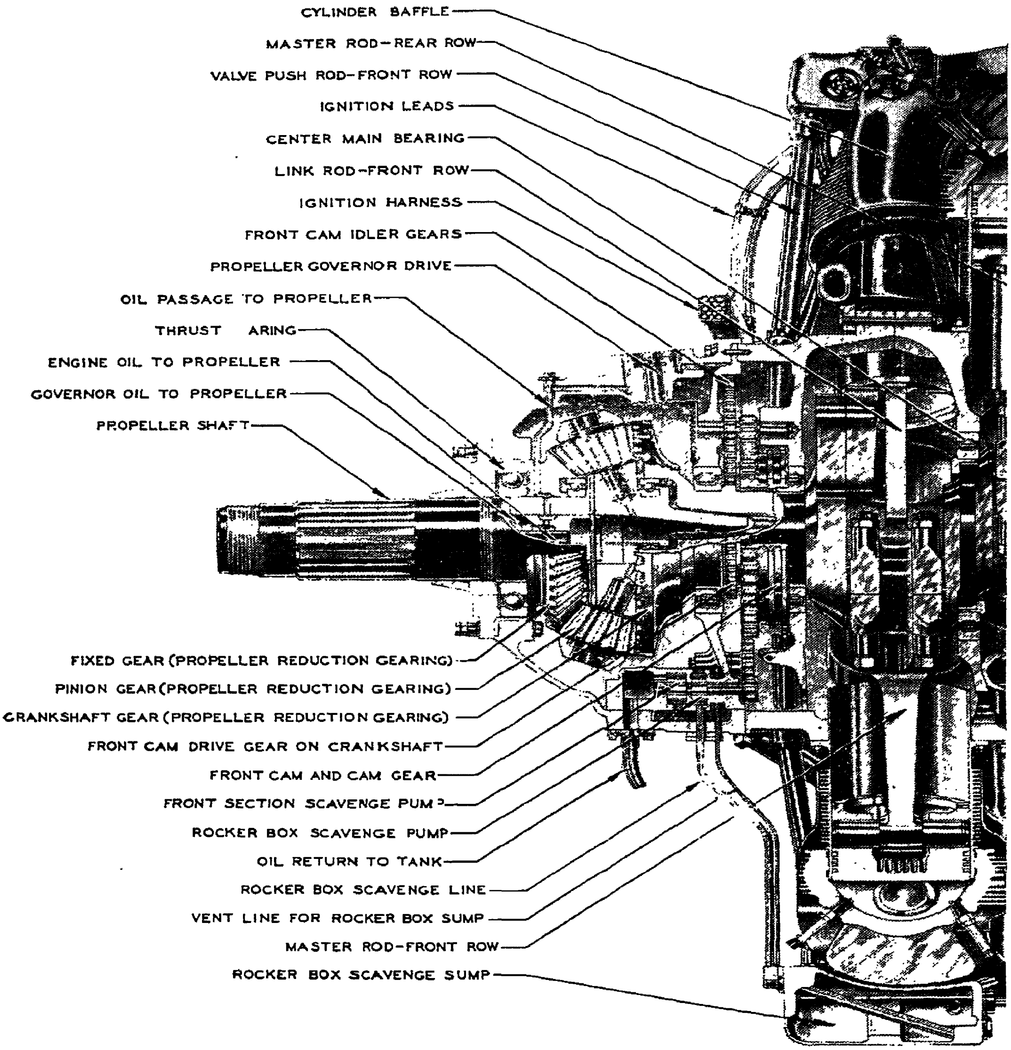
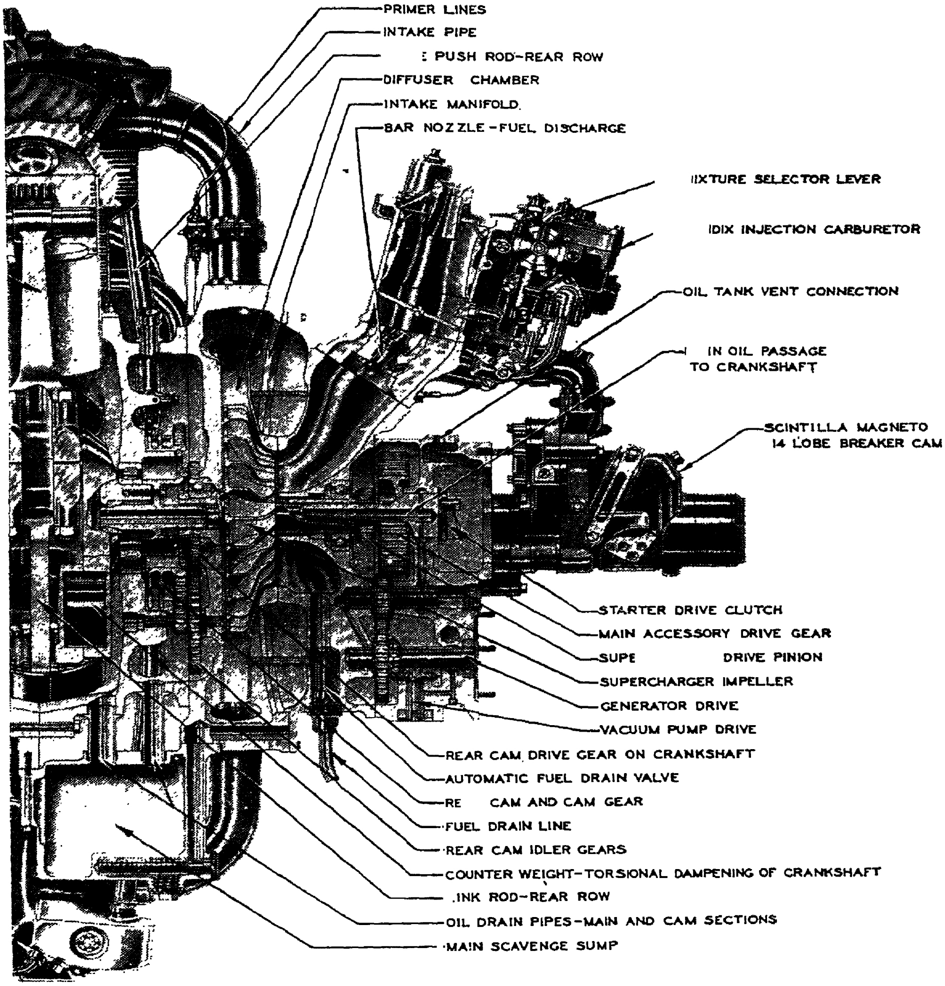


FIG. 304.—Cross-section of a Pratt

Many forms of fuel gauges are used to indicate the quantity of fuel. The float type with the indicator rod sticking up through the tank cap is common on small planes. Large planes

employ the electrical gauge described in Chap. VI, Electricity. This gauge usually has only one instrument with a tank selector switch.

Most planes are equipped with primers to inject raw fuel into



and Whitney twin-row engine.

the cylinder for starting. These are small hand pumps located in the cockpit or nacelles and are connected to the fuel supply line.

The induction system on small airplanes is very simple. Intake air is drawn through the carburetor and into the intake

manifolds by the pistons. In the carburetor the proper amount of fuel is added by the metering action of the carburetor. In simple engines maximum horsepower is developed at sea level. As the atmospheric pressure and the air density decrease with altitude, the horsepower will also decrease. Such simple engines are not altitude engines.

The larger horsepower engines used on modern transports and military planes are required to fly at high altitudes, particularly the high-altitude bomber. If these engines relied on the

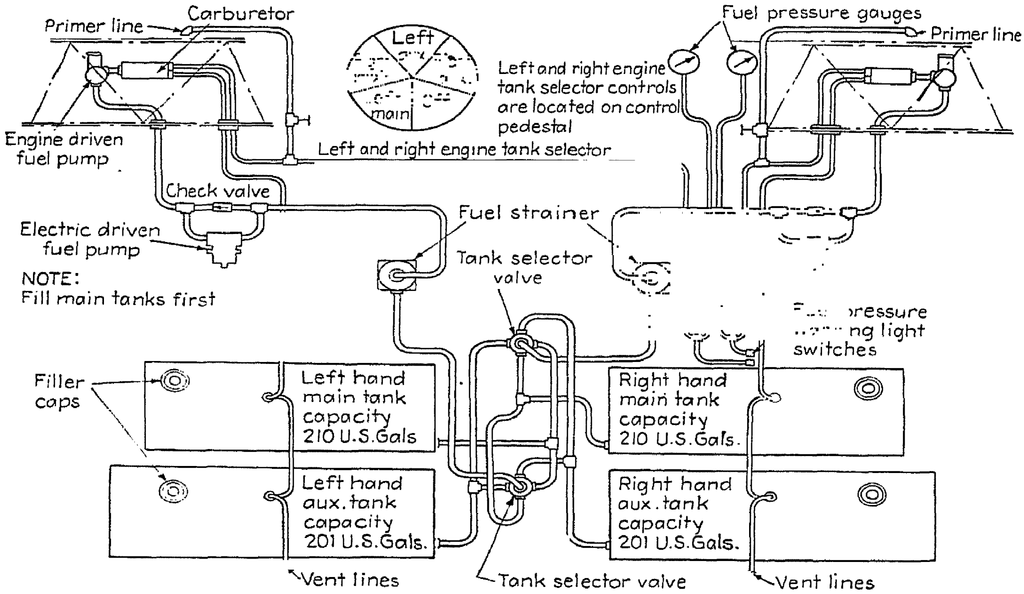


FIG. 305.—Douglas DC-3 fuel system with electric auxiliary pumps.

simple induction system mentioned in the previous paragraph, they would never reach their operating altitude. To overcome the loss of horsepower due to the decrease in air density, the outside air is packed into the engine by means of a supercharger. This supercharger is a veined disk or impeller geared to turn at many times crankshaft speed. It is located between the carburetor and intake manifolds. It draws air in through the carburetor and forces it out through the diffuser veins. The metering action of the carburetor is the same as for the simple system. The faster the supercharger rotates, the more air is packed into the engine. This makes it possible to obtain a

constant manifold pressure up to the critical altitude of the engine. This is the altitude at which the supercharging effect begins to fall off and the horsepower decreases as under normal conditions.

Since it is possible to obtain too much manifold pressure at sea level and thus damage the engine, the amount of manifold pressure must be limited. A gauge, connected to the diffuser section, is placed in the cockpit so that the pilot can obtain the correct manifold pressure for all conditions

Most fuel tanks are aluminum-riveted and welded tanks. Some are made out of turnsheet or stainless steel. The fuel is conducted from the tanks to the carburetor by means of aluminum and copper tubing and rubber hose. Sections of the tube are connected with tube connectors or rubber hose.

The Simple Carburetor

Modern carburetors, though complicated, still operate on the simple principles of carburetion. This discussion is for the simple carburetor only.

The carburetor is a device for metering the correct quantity of fuel and mixing it with the air passing through it to form a combustible vapor. Gasoline will burn if mixed with about eight to sixteen times its own weight of air. However, best performance is obtained with about 15 parts of air to 1 part of gasoline. Air-cooled engines because of their higher head temperatures require a slightly richer mixture than liquid-cooled engines.

The simple float type of carburetor consists of three main parts, the float chamber, the Venturi, and the jet. One form of this carburetor is shown in Fig. 306.

Fuel from the supply tank enters through the float valve, raising the float until the float valve is closed and the flow of fuel is cut off.

Incoming air passing through the restricted throat of the Venturi must travel at a higher rate of speed than air traveling through a uniform tube. In Chap. III it was learned that velocity times pressure is equal to a constant for an air channel. Therefore, the pressure in the Venturi must be less than for air passing through a uniform tube. This reduction in pressure causes gas to be drawn from the float chamber and forced out the discharge nozzle into the air stream. When the throttle

is opened wide, the amount of air passing through the Venturi is increased and the amount of gasoline discharged is greater. When the throttle is closed, the reverse is true.

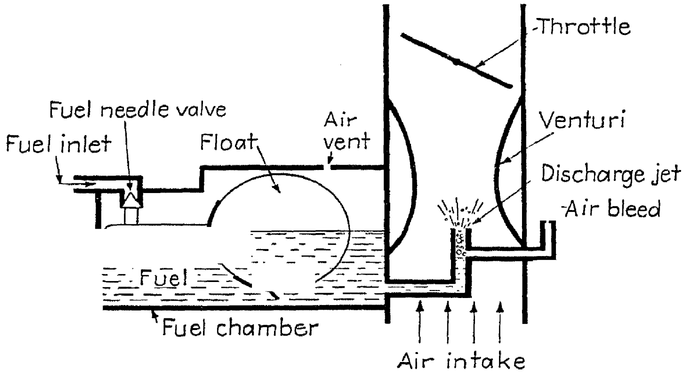


FIG. 306.—Simple carburetor.

Air Bleed.—When the engine speed is decreased, jet delivery falls off because of the tendency of the fuel to cling to the nozzle and the amount of suction lost in raising the fuel from the float level up to the nozzle. This is corrected by placing an air bleed

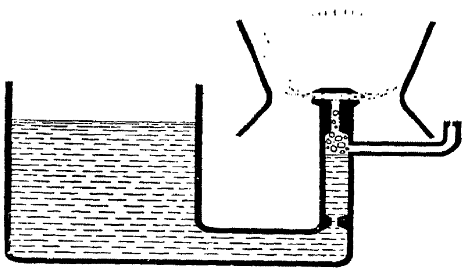


FIG. 307.—An air bleed added to the simple carburetor to emulsify the gasoline. (*Courtesy of Bendix Stromberg.*)

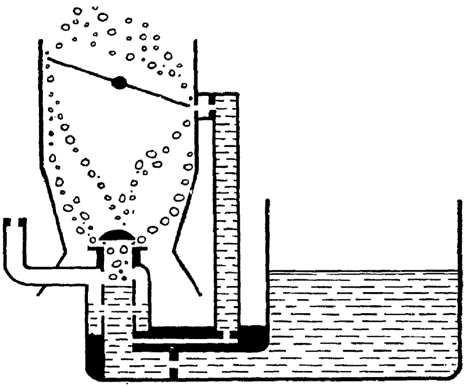


FIG. 308.—Accelerating well with main discharge jet and idling passage. (*Courtesy of Bendix Stromberg.*)

in the discharge nozzle below the fluid level (see Fig. 307). This arrangement emulsifies the gas into small droplets, which permits the gas to be lifted much higher than is possible with solid fluid and the same amount of suction. By placing the jet

on the atmospheric side of the throttle in the center of the Venturi, approximately uniform mixture can be obtained throughout the power range of the engine.

Idling Jet.—When the engine is operating at low or idling speeds, the throttle is almost closed and the force of the air through the Venturi is not sufficient to carry fuel to the throttle. To overcome this, a special passage is provided to carry fuel from the metering tube to the top side of the throttle, an arrangement called the *idling passage* and *jet*, shown in Fig. 308. When the throttle is opened and engine speed increases, this jet ceases to operate.

Accelerating System.—When the throttle is opened quickly, there is a temporary lag in the increase of fluid flow. This lag, or temporary "leaning" of the mixture, can be avoided by the use of an accelerating well or pump. The well is just an enlarged air-bleed chamber. When the suction on the main jet is increased, fuel is drawn from this chamber temporarily to supplement the fuel delivered through the metering orifice.

Engines with long manifolds require greater quantities of fuel than can be supplied by the accelerating well. Such systems employ accelerating pumps like the one shown in Fig. 309. This pump is attached to the throttle, so that when the throttle is opened the sleeve is depressed, forcing fuel through the second passage and out the discharge nozzle.

The Economizer System.—Since it is desirable to have a lean mixture for maximum economy at part-throttle or cruising speeds and a much richer mixture for maximum power and the cooling of air-cooled systems at full throttle, an economizer system is used. These systems in their present forms are in reality enriching devices for high speeds or full throttle. One of these systems is shown in Fig. 310. It is a needle valve operated by the throttle at a predetermined throttle position to permit a quantity of fuel to be drawn into the air in the carburetor, in addition to that furnished by the main metering system.

In Fig. 311 a piston type of economizer is shown. The lower piston acts as a fuel valve to prevent the flow of any additional fuel at part throttle or cruising speed. The upper piston permits air to be drawn in through the small holes. When the throttle is open, the pistons are lowered, uncovering the lower part, and

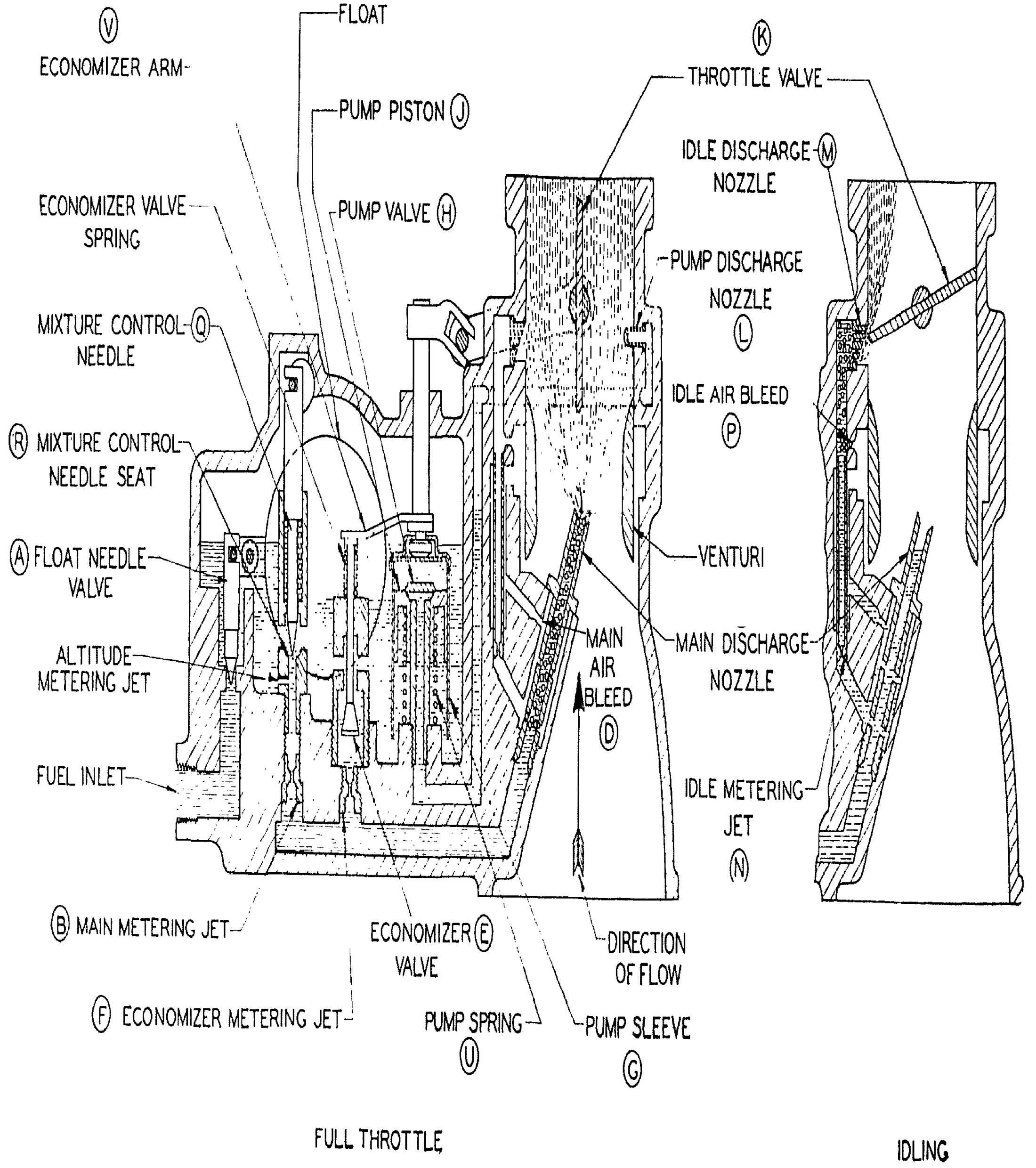


Fig. 309.—Showing an accelerating pump operated by the throttle. (*Courtesy of Bendix Stromberg.*)

fuel is thus permitted to flow out the economizer discharge nozzle. At the same time, the air bleeds are closed, thus increasing the suction on the fuel jet.

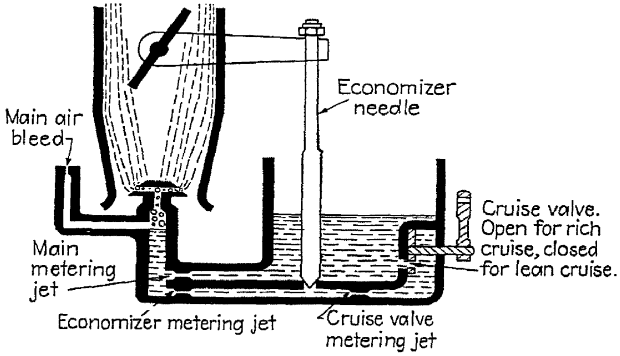


FIG. 310.—An economizer jet and needle. The needle is operated by the throttle. (*Courtesy of Bendix Stromberg.*)

Mixture Control.—Atmospheric pressure decreases in temperature and density with an increase in altitude. The weight of the air charge also decreases with a decrease of air density, reducing the power output of the engine. Therefore, the mixture delivered to the engine becomes richer. In order to compensate

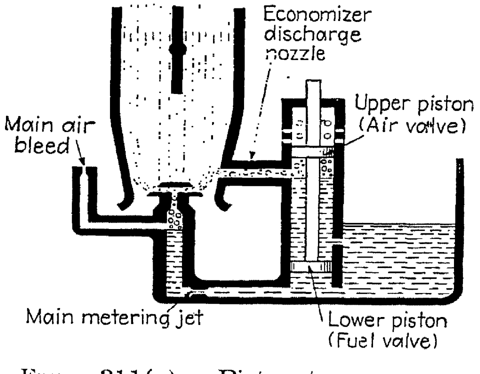


FIG. 311(*a*).—Piston-type economizer operated by throttle with main discharge jet. Full throttle. (*Courtesy of Bendix Stromberg.*)

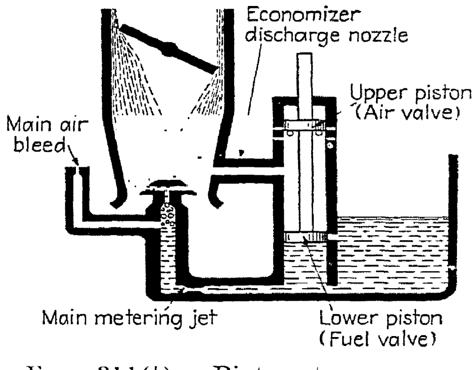


FIG. 311(*b*).—Piston-type economizer operated by throttle with main discharge jet. Part throttle (cruising).

for this enriching, a mixture control is provided on most aircraft carburetors. The lower priced carburetors employ manually operated mixture controls. The higher priced carburetors for larger horsepower engines employ automatic mixture controls.

Figure 312 shows a back-suction type of mixture control. This type of control has an air passage from the top of the float chamber to the throat of the Venturi. When the valve in this passage is closed, the carburetor is operating under normal conditions. When it is opened, the pressure in the float chamber is decreased owing to the suction which exists at the jet. This decrease in the pressure in the float chamber will oppose the suction at the main discharge nozzle and will decrease the fuel flow.

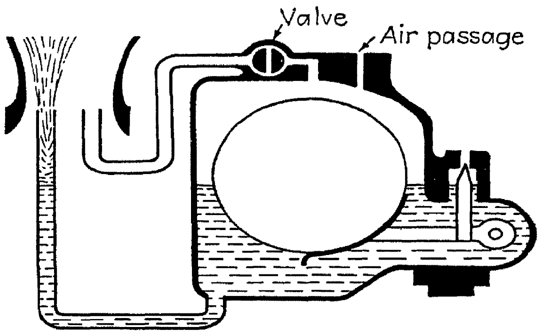


Fig. 312.—Mixture-control valve in suction passage. Full rich position. (*Courtesy of Bendix Stromberg.*)

Ignition System

The ignition system requires a means of producing a high-tension current, spark plugs, and a switch to render the system inoperative or operative. Although battery systems have been used, the magneto is by far the most prevalent. Some ignition cables are incased in metal tubes and flexible metal hoses to prevent wear and radio interference. These assemblies are known as *ignition harnesses*, and the cable is said to be *shielded*. Engines of 65 hp. or better have two magnetos for added safety and more even burning of the gases within the cylinders.

Magneto.—The basic theory behind the operation of the magneto was developed in Chap. VI, Electricity, except for several refinements peculiar to the aircraft magneto. The aircraft magneto consists of a four-pole magneto rotating between two pole shoes tied together at the top by a soft iron coil core. A schematic diagram of an aircraft magneto is shown in Fig. 313.

The *primary winding*, made up of a few turns of copper wire, is wound directly on the core. As the magneto rotates, a

current is induced in these coils as if the coils were rotating between the two poles of a horseshoe magnet.

One end of the primary coil is grounded to the core piece. The other end has two connections. One connection goes to the magneto switch in the cockpit, and the second to the breaker points attached to the rotating magnet.

A condenser is placed in this circuit. One side is connected to the primary; the other is connected to the ground.

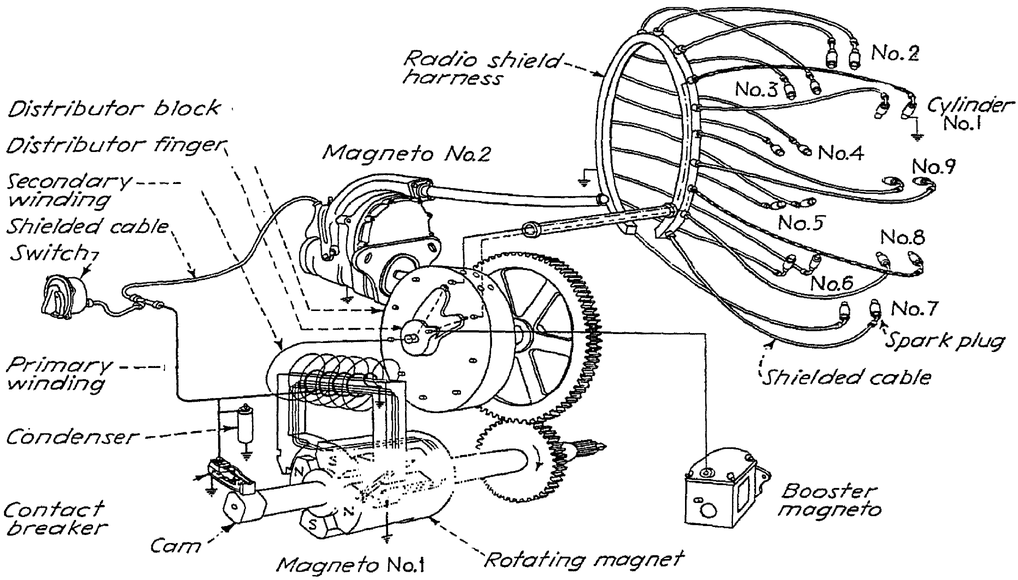


FIG. 313.—Typical aircraft magneto. (*Courtesy of Bendix-Scintilla Mfg. Co.*)

As long as the breaker points remain closed, rotation of the magnet will induce current in the primary coil. Because of the four poles, current will reach a maximum value, decrease to zero, and reverse direction every 90°, or four times each revolution. These reversals will produce an alternating current in the coil. The induced current in the coil will produce a magnetic field in the coil that will tend to oppose any change in the line of flux. This resistance to the change of flux will store up the flux.

When the contact points are opened, the primary circuit is broken, the flow of current in the primary ceases, and the magnetic field set up by it is removed. This releases, in a very short period of time, the flux that has been stored up, producing a

high rate of change in flux density and thus inducing a high voltage in the secondary winding. This is a winding of many turns of fine wire wound over the primary.

Hence it can be seen that the purpose of the primary coil is to maintain the flux at a high value, and the purpose of the breaker points is to release the flux as quickly as possible to produce the high voltage in the secondary. The contact points are timed to open when the maximum voltage will be induced in the secondary winding. These positions have been determined by the designer and are given in degrees of rotation of the magneto past the neutral position. This is referred to as the E gap.

When the high voltage in the secondary winding discharges, a spark will jump the gap of the spark plug. This ignites the fuel in the cylinder, producing power. Should the wiring or the plugs in the secondary circuit be damaged, thus preventing the discharge of the high voltage, the magneto will be damaged, also. To prevent this a safety gap has been placed in the circuit to discharge the current before damage is done. This gap offers greater resistance than the spark plug but less than the magneto.

When the contact points are opening, the current in the secondary induces a current in the primary. This current produces an arcing at the breaker points, resulting in an excessive pitting or burning of the points. To prevent this a condenser has been placed in the primary circuit to absorb the induced current.

The high-voltage current is directed to the proper spark plug at the proper time by means of a distributor attached to the front of the magneto. From the distributor the current is conducted through a high-tension cable to the spark plug.

Magneto Switch.—The magneto switch in the primary circuit is grounded on one side. When the switch is placed in the "Off" position, the primary current is connected directly to the ground. When the contact points are now opened, the field does not collapse. Therefore, the high voltage is not induced in the secondary.

Booster System.—To facilitate starting, some systems employ a booster high-tension coil. It operates off the battery system to furnish high-voltage current to the cylinder just fired before the present cylinder being fired by the magneto. This lag is to

prevent backfiring and possible damage to persons or property. In Fig. 313, the booster is shown connected to the magneto.

Ignition Wiring.—The high-tension ignition wires connecting the magneto and the spark plugs or the booster and the magneto are made up of many small wires wound together and heavily insulated. The insulation on these wires is very important and must not be damaged, or a short circuit will result. Once a high-tension cable has been damaged, it cannot be repaired

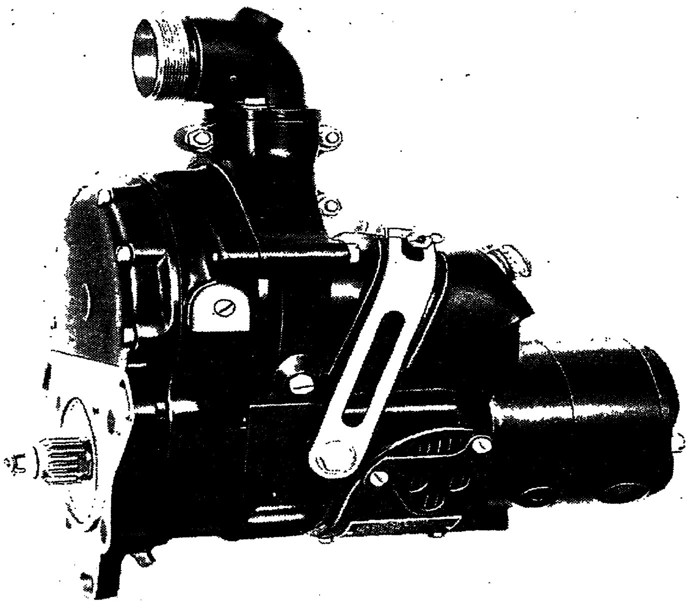


FIG. 314.—A Scintilla SF14LN-3 magneto used on Wright and on Pratt and Whitney radial engines.

(unless it is close to the ends) but must be replaced. This entails considerable time and labor; therefore, every effort should be made to protect the ignition cable from possible damage.

The low-tension ignition wires are used to conduct current to the booster from the battery or as a ground for the magneto primary circuit. These wires have a few strands of wire wound together and are lightly insulated.

The magneto harness is composed of three parts, the lead from the magneto to the manifold, the manifold, and the leads from the manifold to the plugs. The leads are flexible brass or stainless-steel braid tubing. The manifold is square, round, or oval

aluminum, brass, or stainless-steel tubing. Inside this tubing the ignition cables for all the spark plugs are inserted. When the cable reaches a point in the manifold opposite the appropriate cylinder, it is drawn out of the manifold and routed through the flexible cable or conduit to the proper spark plug.

The harness prevents damage to the ignition cables and reduces radio interference. This is called *shielding*. The plugs and magnetos must also be shielded, and all shielding must be grounded to be effective.

Spark Plugs.—Spark plugs are used to convert the high-voltage current of the secondary winding into a spark to ignite the fuel mixture in the cylinders. This is produced by the current jumping the air gap between the electrodes of the spark plugs. The spark plugs are located on the front and rear of each cylinder head on dual-ignition engines to give a more even burning.

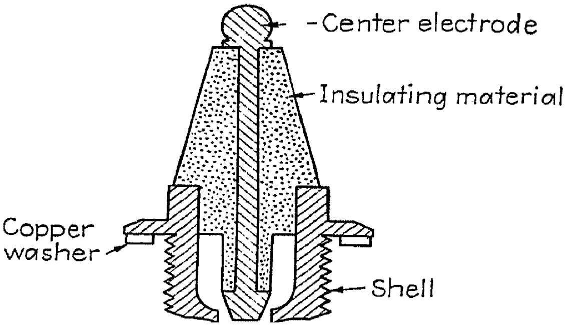


FIG. 315.—Typical aircraft spark plug.

Many types of spark plug are manufactured. They may be shielded or unshielded. In general, a spark plug has two electrodes. A typical spark plug is shown in Fig. 315. One electrode is the shell, which is screwed into the spark-plug insert of the cylinder head. The other electrode, or high-tension lead, forms the center of the plug. The ignition cable is fastened to this. Between the two electrodes is some form of insulating material, which may be a ceramic material or mica washers. The mica-washer plug may be disassembled for cleaning of the points and adjustment of the gap. The proper gap setting is important. If the gap becomes too wide, the spark may be too weak to furnish the proper ignition at high engine r.p.m.

LUBRICATING SYSTEM

Moving parts create friction, which causes a loss of useful horsepower, excess heat, and wear of the moving parts. When the temperature of two dissimilar metals is increased, one metal will expand more than the other. Should the increase in tem-

perature be large, the metal parts may seize, or "freeze up," rendering the engine useless. To overcome frictional losses and reduce wear to a minimum, lubricating oil is used on all moving parts.

Engine oils play an important part in the high efficiency of the present-day aircraft engine; no engine will continue to operate long without them. Oils are classified by viscosity. Light oils have low viscosity. Heavy oils have high viscosity. In the United States, viscosity is measured by means of the Saybolt viscosimeter, which measures the time in seconds required for 60 cc. of the liquid being tested to flow through a small tube.

The oil being used in the engine must be the correct oil specified by the manufacturer. The manufacturer has special equipment for the determination of the correct oil to be used to ensure proper lubrication of all parts at the operating temperatures of the engine. Not only does oil lubricate all moving parts to help eliminate friction, but also it helps to cool these moving parts. This is a very important item, particularly in the air-cooled engine.

The small-horsepower engines may have either a wet or a dry sump. In either case the oil is retained with the engine, not in a separate tank. An oil pump, usually the gear type, draws oil from the sump and forces it through the passage in the crankcase to the accessory drives, bearing journals, and cam followers and out to the rocker arms. Excess oil draining back to the crankcase by gravity is broken into a fine spray and is deposited by splash on the cylinder walls to lubricate the piston and rings.

Larger aircraft engines, particularly the radial, employ the dry sump and a separate oil tank. Oil is drawn from a tank by a gear-driven oil pump and forced past a pressure relief valve into the engine. The pressure relief valve relieves all excess pressure back to the pump or to the sump. (The low-price engines also have this valve.) The oil under pressure is forced through the passages in the case to the accessory drive gears, the bearing journals, the cam followers, the propeller governor, and the overhead valve mechanism. Oil draining back to the crankcase is broken into a fine spray that oils the cylinder walls, piston, and rings. It drains by gravity back to the sump, where the scavenger pump returns it to the oil tank via a temperature

regulating valve and oil radiator. The scavenger pump, or return pump, has a much larger capacity than the pressure pump because the oil is now emulsified with air.

The temperature regulating valve is an automatic sylphon type of valve (Fig. 316) that by-passes the oil radiator until the oil has reached the operating temperature. This valve shortens the run-up period.

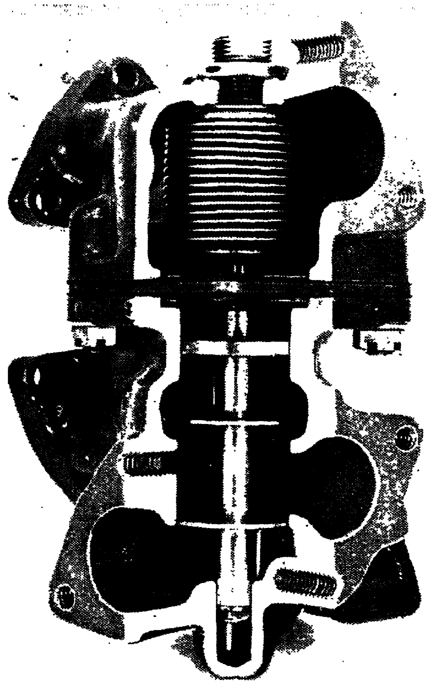


FIG. 316.—A cross-section of an oil-temperature regulator located on top of the oil radiator. (*Courtesy of Eastern Air Lines, Inc.*)

The oil radiator reduces the oil temperature to keep it within the required operating temperature. If the temperature of the oil becomes excessive, its viscosity will be greatly lowered and undue wear or possible failure will result.

When the engine first starts, the oil is cold and thick. This prevents it from satisfactorily reaching all parts requiring lubrication. As a result, parts may be damaged before the temperature of the oil is raised to a value sufficient to ensure safe lubrication. In order to prevent this, the oil-dilution system is used. Gasoline is mixed with a small quantity of oil in a hopper inside the oil tank, and thus the oil is diluted and its viscosity reduced. The diluted oil is drawn into the engine first, to ensure satisfactory lubrication until the remaining amount of oil can be brought up to the proper temperature. After a short period of run-up, all dilution has been eliminated.

Oil tanks are usually aluminum and are located either on the engine mount or in the nacelle. The CAA specifies the minimum quantity of oil to be carried for each engine. This is at least 1 gal. per 75 hp. In addition, the tank must be built 10 per cent larger than the quantity of oil to be carried, to allow for expansion and frothing of the oil.

APPENDIX

AN STANDARD PARTS IN COMMON USE

Bearings:	
Aircraft	AN200
Bolts:	
Hexagonal head, aircraft, drilled for cotter pin	AN3 to AN16
Clevis	AN23 to AN36
Eye for pin	AN42 to AN49
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